(4)

Technical Report 1349
June 1990

Use of Marine Fouling Communities to Evaluate the Ecological Effects of Pollution

R. K. Johnston

NAVAL OCEAN SYSTEMS CENTER
San Diego, California 92152-5000

J. D. FONTANA, CAPT, USN
Commander

R. M. HILLYER
Technical Director

ADMINISTRATIVE INFORMATION

This work was performed by the Marine Environment Branch, Code 522, Naval Ocean Systems Center, for the Naval Facilities Engineering Command.

The information in this report was originally presented by the author for partial fulfillment of the requirements for the degree of Master of Science in Biology at San Diego State University, San Diego, CA.

Released by
P. F. Seligman, Head
Marine Environment Branch

Under authority of
S. Yamamoto, Head
Environmental Sciences Division

ACKNOWLEDGMENTS

I especially wish to thank my committee members Drs. Richard Ford, Stuart Hurlbert, and James Mathewson from San Diego State University and Dr. Alberto Zirino from the Naval Ocean Systems Center for their continued guidance and support in planning and conducting this research and in careful and detailed reviews of the manuscript.

I would like to acknowledge the encouragement I received from Larry Gadbois and Manchi Gadbois, whose moral support and understanding made accomplishment of this task possible. I also thank Peter Stang for help in field work, organotin analysis, manuscript review, and inspiration; Anthony Jones for help in the initial conception of the study, underwater photography, and species identification; Ruth Fuhrmann for ICP analysis of copper samples; Aldis Valkirs, Giti Vafa, Martha Stallard, and other members of Team Hydride for analysis of organotin samples; Sandra Salazar, Michael Salazar, Bradley Davidson, and other members of the PETS Team for support and assistance in the microcosm study; David Bower for assistance with the MESC survey and data analysis; Kenneth Richter and Cynda Maxson for encouragement, critical review of early drafts of the manuscript, and laser printing; Elaine Corets for help with bryozoan identification; and Linda Oestreich for editorial review of the manuscript and teaching me valuable technical writing skills.

I also acknowledge the support provided by the Naval Ocean Systems Center, which made possible the planning and execution of this research. I sincerely thank Peter Seligman and Sachio Yamamoto for their managerial support and understanding in allowing me to achieve my research goals. This project was funded in part by the Marine Environmental Quality Assurance Program and the Marine Environmental Support Office with funding provided from the Naval Facilities Engineering Command.

JG

SUMMARY

The ecological consequences of pollution were evaluated by measuring the biological responses of marine fouling communities to increasing levels of pollution in a yacht basin in San Diego Bay, California. Measurements of a gradient of increasing levels of copper and organotin compounds were made using anodic stripping voltammetry (ASV) and inductively coupled plasma spectroscopy (ICP) for copper and hydride derivation with atomic absorption spectroscopy detection for the organotin compounds tributyltin (TBT), dibutyltin (DBT), and monobutyltin (MBT). Community composition of epibenthic organisms along this gradient was determined by placing plexiglass panels at four stations corresponding to low, medium, high, and very high concentrations of copper and organotin pollution along the gradient. A portable microcosm system containing twelve 340 l aquaria was used to study the community responses to different concentrations of TBT (0.006 to 0.200 µg/l) in a controlled environment.

Mean copper concentrations within the field gradient determined by ASV ranged from 2.63 to 11.07 µg/l along the gradient. Mean concentrations of copper determined by ICP ranged from 5.13 to 11.75 µg/l. For the organotin compounds, mean TBT concentrations within the gradient ranged from 0.04 to 0.35 µg/l, mean DBT concentrations ranged from 0.03 to 0.32 µg/l, and mean MBT concentrations ranged from 0.02 to 0.09 µg/l along the gradient. Most of the copper measured was present in dissolved or labile form, suggesting that copper was biologically available to the marine organisms in the yacht basin. There was an indication that the rate of degradation of TBT to DBT and MBT was relatively constant and proportional to the concentration of TBT present. Tidal change was identified as a major source of variability in the chemical concentrations.

Differences in community structure were correlated with distinctly higher concentrations of toxic chemicals present at these locations. The communities of organisms associated with the lowest levels of copper and organotin compounds were characterized by the codominance of the bryozoan *Bugula neritina* and the tube-building polychaetes *Hydroides pacificus* and *Spirorbis* sp., a mean number of 11.83 species/50 cm^2, and more curved dominance-diversity (Whittaker) curves. The communities associated with higher levels of copper and organotin compounds were dominated by polychaetes, had a mean of 6.17 species/50 cm^2, and exhibited straighter dominance-diversity curves, suggesting geometric series. In general, mean biomass density increased from 40.55 to 74.5 g/500 cm^2 as the level of copper and organotin compounds increased, except for the highest levels of pollution. At those highest levels, mean total biomass was 36.09 g/500 cm^2.

The microcosm system was not effective in determining the response of fouling communities to increased levels of TBT. This was due primarily to low levels of settlement by fouling organisms on panels in the tanks relative to their settlement and colonization on panels in the bay. The low settlement was attributed to the high biomass maintained in the tanks, inadequate flow rates in the microcosm system, destruction of larvae by the pumping system, larval avoidance of the intakes to the microcosm system, or a combination of these factors.

CONTENTS

CONTENTS (continued)

FIGURES

CONTENTS (continued)

FIGURES (continued)

CONTENTS (continued)

TABLES

INTRODUCTION

PURPOSE

The effects of pollution are assessed by determining changes in biological and environmental characteristics of the system. The effects of gross environmental impacts are usually fairly evident; however, the ecological effects of subtle, chronic, and irregular insults are more difficult to distinguish from changes caused by natural processes. Data on chemical concentration and laboratory toxicity alone are not always reliable predictors of the biological consequences of pollution (Long and Chapman, 1985).

Changes in community composition of marine fouling organisms, or species which inhabit submerged dock and piling structures, were used to evaluate the ecological effects of increasing levels of copper and organotin compounds in a yacht basin in San Diego Bay, California. A gradient of increasing levels of these toxic chemicals, occurring within the Shelter Island Yacht Basin (figure 1), was selected as the specific site for the study. Community composition of epibenthic organisms was measured by placing plexiglass panels at four stations corresponding to low, medium, high, and very high concentrations of copper and organotin compounds along the gradient. In addition, an artificial gradient of organotin compounds, produced within a portable microcosm system located at the Naval Amphibious Base, was used to study the community responses in a controlled environment (figure 1).

The chemical gradient in the Shelter Island Yacht Basin existed over a distance of approximately 2 km, extending from the main channel of San Diego Bay into the Shelter Island Yacht Basin (figure 1). Previous studies showed that there was about a 10-fold increase in dissolved organotin and copper compounds between the main San Diego Bay entrance channel and inner portion of the yacht basin (Zirino et al., 1978; Lane, 1980; Zirino and Seligman, 1981; Stang, 1985; Grovhoug et al., 1986; Seligman et al., 1986; Valkirs et al., 1986; Grovhoug and Seligman, 1987; Seligman et al., 1989). The primary sources of these contaminants were presumably the antifoulant coatings on the large number of boats berthed within the yacht basin (Young et al., 1979; Lieberman et al., 1984; Henderson, 1985; Seligman et al., 1986a; Paul and Davies, 1986; Grovhoug et al., 1986).

The portable environmental test system (PETS), contained twelve 340 l aquaria that were used as part of a research and development project, conducted by the Naval Ocean Systems Center (NOSC), to assess the effects of tributyltin (TBT) on marine organisms at environmental concentrations (Zirino and Johnston, 1984; Henderson, 1985; Salazar et al., 1987a; Salazar et al., 1987b). Settlement and colonization of fouling organisms exposed to three treatment concentrations of TBT were measured on panels placed in the PETS tanks.

The study described in this report was designed to answer the following basic questions:

1. What were the levels and variability of the concentration gradient of copper and organotin compounds within the Shelter Island Yacht basin over the study period?
2. What copper fractions and organotin compounds were present in the water column?
3. Do differences in composition of fouling communities exist along the gradient of increasing copper and organotin concentrations within the Shelter Island Yacht Basin?
4. What types and species of organisms would be more successful under conditions of these increased levels of chemical pollution?
5. Can microcosm experiments be used to predict the responses of fouling communities to tributyltin (TBT), a component of the yacht basin pollution gradient?

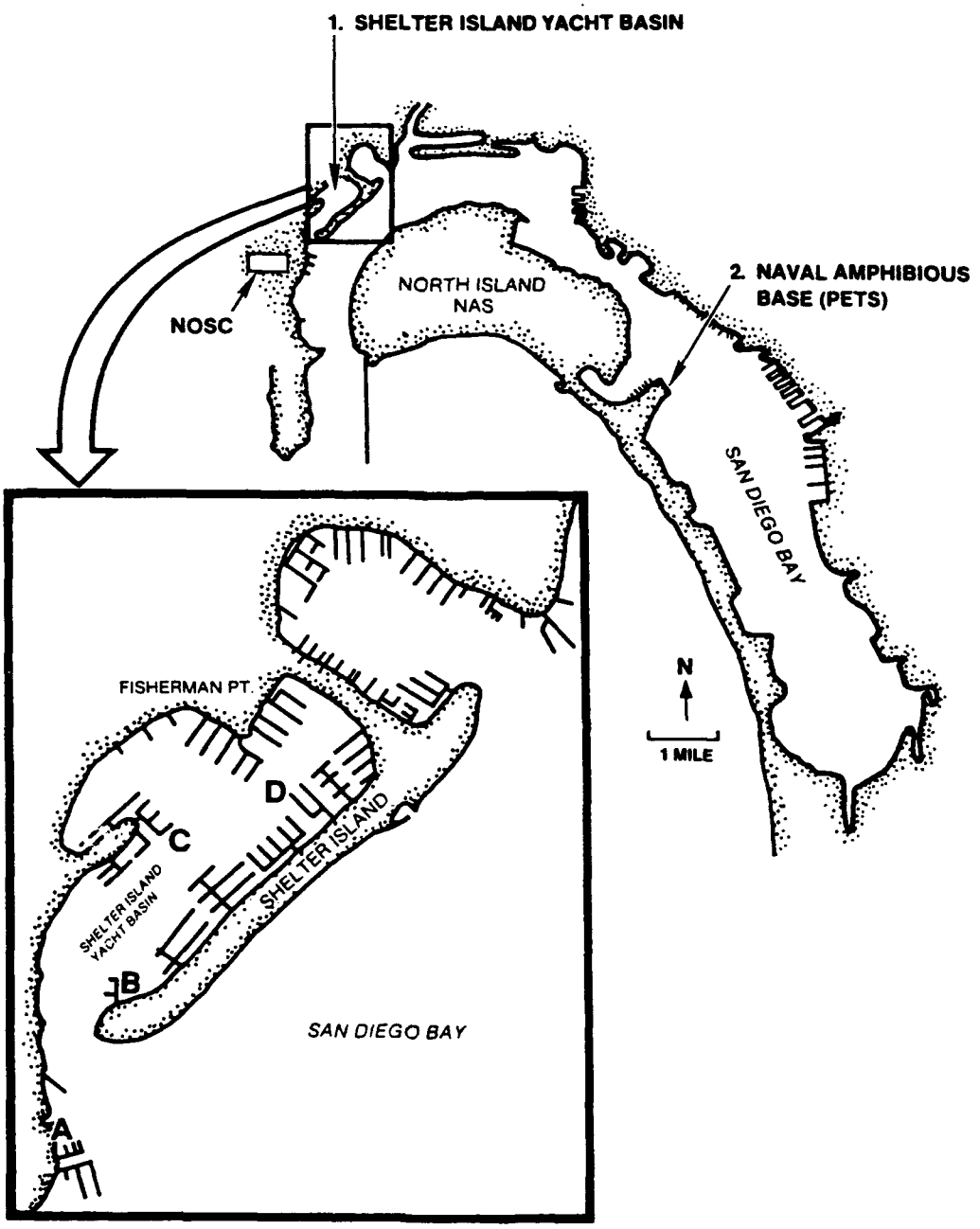


Figure 1. Location of the Shelter Island Yacht Basin (1) and the portable environmental test system (2) in San Diego Bay, California. The location of the field monitoring stations are identified in the Naval Ocean Systems Center, Pier 159 (A), the Harbor Police boat dock (B), slip D-62 of the Southwestern Yacht Club (C), and at the end of the Silvergate Yacht Club Pier (D).

6. Can differences in marine fouling communities, measured in the field and within microcosm systems, be used as an indication of the ecological effects of pollution?

EVALUATING TOXICITY TO MARINE ORGANISMS

To determine the degree of "biologically damaging excess" (Long and Chapman, 1985) from pollution, quantitative biological data must be obtained. Three objectives must be met to effectively determine the extent of pollution: (1) formulating and testing hypotheses, (2) validating laboratory results with measurements of the field response of organisms to pollutants, and (3) relating measured responses to important biological processes, such as growth, reproduction, and survival (White and Champ, 1983). A common approach in detecting effects of pollution on natural ecosystems is to use measures of community composition, such as diversity or similarity indices (Washington, 1984), or to use data for indicator species whose presence absence, or abundance are used to relate environmental quality to laboratory derived toxicity levels for that species (Washington, 1984; USEPA, 1968).

However, changes in diversity indices tell almost nothing about biological processes (Hurlbert, 1971). Moreover, toxicity data derived from laboratory bioassays are subject to wide variations due to age, sex, genotype, acclimation of the organisms to experimental conditions, and the length of the test (White and Champ, 1983). For these reasons, laboratory bioassay data are not sufficient to determine if there is a pollution effect under field conditions (Grassle and Grassle, 1984; Donaghay, 1984; Salazar and Salazar, 1987). In addition, indicator species work well for only specific toxicants and their populations may be highly influenced by natural variations in population processes such as recruitment and predation (Gray, 1981; Washington, 1984; Levin, 1986).

In order for assessments of chemical pollution to be ecologically relevant, the effects of the toxic substances must be determined for the different life stages of the test species (Epifanio, 1984). These assessments must also account for the natural conditions such as the biological availability of the toxicant (Salazar, 1986), and the acclimatization of the animals to the polluted conditions (Beaumont and Budd, 1984). Even assessments which encompass these factors will provide only an "...incomplete idea of how pollution affects animals in [their] natural environment" (Epifanio, 1984, p. 509). Pollution assessment strategies must measure the level of contamination, relate contamination levels to the known toxicological response of the pollutant, and measure the biological significance of pollution impact (Long and Chapman, 1985).

STUDY AREA

Specific details about the study area were important in establishing the sampling sites and selecting the sampling regime used in this study. The shape of San Diego Bay, located at 32°40'N latitude and 117°14'W longitude (figure 1), was formed about 10 to 15 million years ago during Pliocene movement of the California crust (Peeling, 1975). The bay exhibits the characteristics of a coastal-plain estuarine system (Gross, 1972), probably formed by alluvial erosion and the subsequent drowning of the Otay, Sweetwater, and San Diego River valleys by rising sea level (USACOE, 1975). The Silver Strand, formed by buildup of littoral materials from the Tijuana River delta (USACOE, 1975), gives San Diego Bay its crescent shape.

Before 1875, a large portion of the bay consisted of salt marsh and tidal flats (USACOE, 1975). In 1875, the San Diego River was diverted into the Mission Bay Channel (Peeling, 1975), and a series of extensive dredge and fill operations has given the bay its present-day shape (Peeling, 1975). Shelter Island and Shelter Island Yacht Basin were constructed during dredging and filling operations conducted by the Army Corps of Engineers in the late 1930s and early 1940s (Peeling, 1975). The

mean depth at mean lower low water (MLLW) within Shelter Island Yacht Basin (figure 1) is about 5 m, with the greatest depth of 7 m at the entrance to the basin, and shallowest at 3 m near Kellogg Beach. The mean width of the yacht basin is 475 m, with an entrance width of 200 m and a widest width of 750 m in the center of the basin. The distance from the main channel to the end of the yacht basin is about 2 km, and the average volume at MLLW was determined to be 5,900,000 m^3.

Cyclical tidal movement of water was very important in selecting the sampling regime used in this study (Gilbert, 1987). San Diego Bay has diurnal and semidiurnal tides, resulting in two high and low tides each day. There is a 14.3-day interval between spring and neap tides (San Diego Unified Port District, 1972). The difference between mean higher high water (MHHW) and MLLW ranges from 1.7 to 2.9 m. The tidal prism is 70,000,000 m^3 or about one-third of the volume of the bay below MLLW (Peeling, 1975). Smith (1972) measured tidal height, temperature, current speed, current direction, salinity, and density at the NOSC pier (figure 1) over a 24-hour period and reported oscillatory currents at the surface and near bottom. He found that minimum flow occurred at the peak of high tide and at the lowest point of low tide, with bottom currents out of phase with the surface currents by 1.5 h. The velocities ranged between 0 to 2.78 km/h and 0 to 1.67 km/h for the surface and bottom respectively (Smith, 1972). Smith also determined that a "two-layer system" exists within the bay from April to November. This system results in the formation of thermoclines and inversions caused by the warmer higher salinity bottom water moving out of the bay. However, during the winter months the bay is nearly isothermal due to cooling and mixing by the wind (Smith, 1972).

FOULING COMMUNITIES

Fouling communities or species associations of epibenthic organisms, which live on docks, piling structures, and boats, were selected for study because they provide a measurable response of a community of organisms to the environmental conditions present. Artificial panels, such as ones used in this study, represent additional space available to fouling organisms and may be used to measure larval settlement, growth rates, changes in species composition, and the presence of life history stages, as well as interactions of colonizing organisms (Coe and Allen, 1937). Surfaces of panels can be thought of as habitats or ecological islands with limited space available for colonization (Osman, 1977, 1982). Because sessile fouling organisms remain at a fixed point, they are subjected to the varying concentrations of toxic chemicals at that point.

Some of the same dynamic processes that occur on natural substrata will also occur on the artificial surface. The artificial surfaces allow replicate measures of the processes which affect settlement, colonization, and survival to be made (Schoener, 1982). Because most fouling organisms are tolerant of a wide range of surfaces, such as wood, cement, and glass, comparable replicate measures of fouling can be obtained by using identical panels (Schoener, 1982).

The composition of species present when the panels are removed for examination can be considered instantaneous "snapshots" of colonization (Osman, 1982). Each replicate sample is subject to settlement by the same set of potential immigrants, if the size and physical environments of the panels are similar. Therefore, the colonization pattern and equilibrium of species present are a result of the processes—immigration and extinction—which have occurred (Osman, 1982). The concentrations of pollutants to which the panels are exposed are part of the processes that determine settlement, colonization, and survival of organisms.

Five important factors which will determine colonization on artificial surfaces are (1) the larval selection of available sites for attachment and settlement, (2) the abundance of larvae present, (3) the interactions among individuals of the same and different species on the artificial surfaces, (4) surface

area available for colonization, and (5) disturbances occurring at the surface of the panels (Osman, 1977).

ENVIRONMENTAL CONDITIONS

Of primary importance in this study were quantitative measurements of the levels of toxic chemicals, which are leached from boat hulls coated with antifouling paints and become concentrated in the water column. The primary active ingredients of antifouling paints currently in use are tributyltin (TBT) and cupric copper (Cu^{2+}). These compounds have been measured in increasing concentrations in San Diego Bay as the numbers of pleasure, commercial, and military vessels in the bay have increased and as the use of TBT- and copper-based antifouling compounds have become more common (Young et al., 1974; Seligman et al., 1986; Grovhoug and Seligman, 1986; Champ and Pugh, 1987).

Figure 2 shows the chemical structure of the organotin compounds TBT, dibutyltin (DBT), and monobutyltin (MBT) (Champ and Pugh, 1987). These chemicals are organometallic compounds and have been shown to be extremely toxic to some marine organisms in laboratory tests (U'ren, 1983; Valkirs et al., 1985a; Salazar and Salazar, 1985; Davidson et al., 1986). The toxicity of butyltins decreases during debutylation when organotin is reduced to inorganic tin.

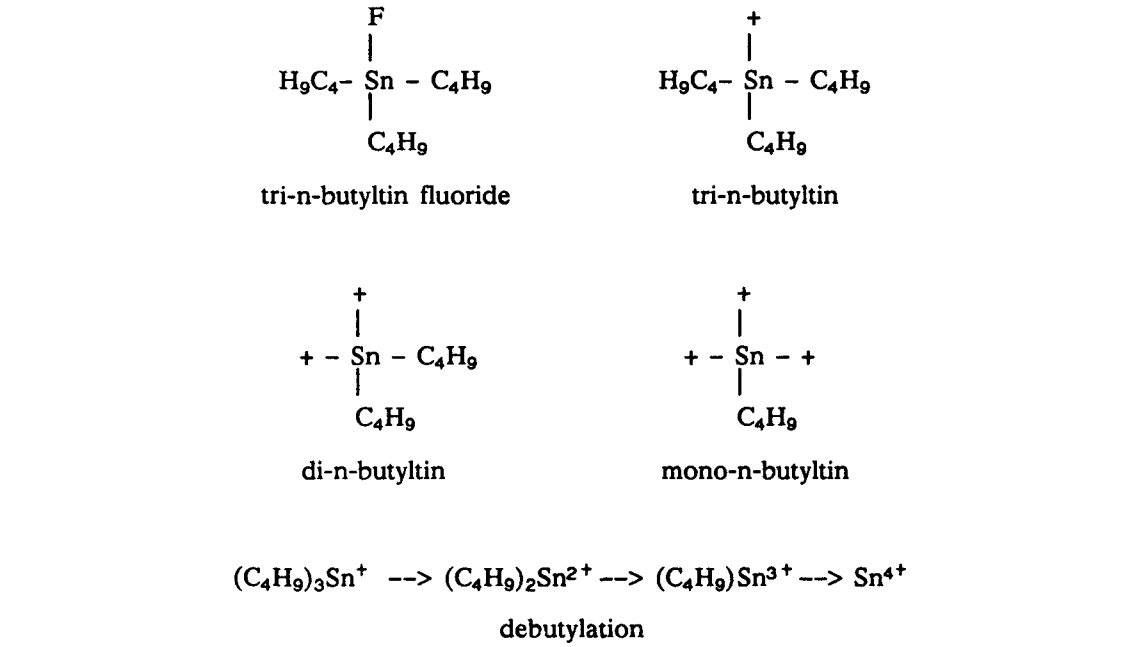


Figure 2. Chemical structure of the organotin compounds tributyltin fluoride (TBTF), tributyltin (TBT), dibutyltin (DBT), and monobutyltin (MBT) and the debutylation process.

Inorganic tin is relatively nontoxic, while TBT is highly toxic due to its solubility in fat and ability to penetrate membranes (Champ and Pugh, 1987). TBT is especially effective as an antifouling agent against molluscs, which do not possess the specialized cytochrome P-450-dependent, mixed-function oxygenase enzyme system shown to be necessary for detoxification of TBT (Lee, 1986).

Studies of acute toxicity of TBT have reported 96-h lethal concentrations for 50% of the test organisms (LC_{50}) of 1.0 µg/l for the copepod *Acartia tonsa* (U'ren, 1983) and larvae of the mussel *Mytilus edulis* (Valkirs et al., 1985a); and 0.42 µg/l for the mysid *Acanthomysis sculpta* (Davidson et al., 1986). Other studies have reported 48-h LC_{50} values of 1.6 and 2.3 µg/l TBT for larvae of the oyster *Crassostrea gigas* and *M. edulis* (Thain, 1986). Studies of sublethal effects from TBT on variables such as reduced growth and reproduction, have documented 50% reduction in growth and fertility (48 h EC_{50}) in *Acartia tonsa* at 0.4 µg/l TBT (U'ren, 1983), in *Acanthomysis sculpta* at 0.14 µg/l TBT (Davidson et al., 1986), and in *M. edulis* at 0.15 µg/l TBT (Valkirs et al., 1986). Another study reported 50% reduction in growth (72 h EC_{50}) after exposure to TBT concentrations of 0.33 and 1.33 µg/l for the diatoms *Skeletonema costatum* and *Thalassiosira pseudonana* respectively (Walsh et al., 1985). Other chronic effects from TBT exposure, such as delayed metamorphosis of mud crab larvae (*Rhithropanopeus harrisii*) after exposure to 10 µg/l TBT (Laughlin et al., 1983) and reverse phototaxis of the water flea *Daphnia magna* when exposed to 0.5 µg/l TBT (Meador, 1986), have also been reported.

Copper is a heavy metal that is an essential nutrient at trace concentrations; however, it has been shown to be toxic at relatively low levels (USEPA, 1985). Copper concentrations in natural waters range from 0.2 to 0.30 µg/l (Boyle and Edmond, 1975; Boyle, 1979), but are higher in coastal areas subjected to pollution impact (Hutchinson, 1979; USEPA, 1985; Johnston et al., 1986).

The form of copper most toxic to aquatic organisms is the ionic (Cu^{2+}) form (Sunda and Guillard, 1976; Andrew, 1977; Dodge and Theis, 1979; Petersen, 1982; Borgman and Ralph, 1984). Relative levels of Cu^{2+} activity can be measured using an ion specific electrode (Zirino and Seligman, 1981; Lieberman et al., 1985; Johnston et al., 1986). Dissolved copper consists of the ionic or labile forms, inorganic complexes and colloids and weak organic complexes, and strongly bound organic complexes and colloids (Zirino, 1981). Seawater analysis at low pH (pH 2) using anodic stripping voltammetry (ASV) measures the ionic and labile fraction as well as copper weakly bound to complexes and colloids (Zirino et al., 1978; Zirino, 1981; Lieberman et al., 1985). Analysis of copper by inductively coupled plasma (ICP) atomic absorption spectroscopy provides a representative measure of the total copper present because the plasma will atomize all the complexes, colloids, and even some of the particulate fraction (A. Zirino, NOSC, personal communication).

The complexing capability, or the amount of colloidal and organic material (e.g., carbonate, phosphate, amino acids, and humates) available to form complexes with Cu^{2+}, is very important in determining the toxicity of copper in seawater (USEPA, 1985). The toxicity of copper in the water column is dependent on the complexation potential, settling rates of the suspended particulate matter, and chemical changes that will alter the dynamic equilibrium of the copper species present. Copper toxicity is often correlated with differences in water hardness or alkalinity, which is known to reduce toxicity (USEPA, 1985).

Acute toxic effects of copper have been reported at LC_{50} concentrations of 5.8 µg/l for the mussel *Mytilus edulis*, at 6.4 µg/l for the water flea *Daphnia magna*, at 7.8 µg/l for the oyster *Crassostrea gigas*, at 17 to 55 µg/l for copepods, at 48 µg/l for larvae of the lobster *Homarus americanus*, and at 200 to 480 µg/l for the polychaete *Nereis diversicolor* (USEPA, 1985). Chronic effects of copper have been reported at concentrations of 38 to 77 µg/l for the mysid *Mysidopsis bahia* (Lussier et al., 1985). Based on the national water quality criteria for the protection of aquatic organisms, marine organisms as a whole are considered to be "safe" if the "acid-soluble" copper concentration does not exceed the 1 h average concentration of 2.9 µg/l more than once every 3 years (USEPA, 1985).

METHODS

STUDY DESIGN

The study consisted of two parts, a field survey conducted at Shelter Island Yacht Basin, and a microcosm experiment performed using the portable environmental test system (PETS) at the Naval Amphibious Base (figure 1). The objective of the field survey was to quantify levels of copper and organotin pollution occurring in Shelter Island Yacht Basin and to determine the fouling community structure associated with increasing concentrations of copper and organotin in Shelter Island Yacht Basin. Another aspect of the study was to determine the effect of tributyltin (TBT) on fouling community development in a controlled microcosm experiment. Comparisons between the results obtained from the field survey and microcosm study would permit inferences to be drawn on the effect of TBT on fouling community development in San Diego Bay.

The sampling regimes consisted of periodic water quality monitoring in Shelter Island Yacht Basin and in the microcosm tanks, exposing plexiglass panels for settlement in the field and microcosm tanks, sampling established fouling communities located at the field stations, and conducting a semi-synoptic water quality survey of Shelter Island Yacht Basin using the Marine Environmental Survey Craft (MESC) (figure 3).

FIELD SURVEY

Biological Data From Panels

Settlement and colonization of fouling communities were measured by establishing four stations within and just outside the Shelter Island Yacht Basin, San Diego Bay, California (figure 1). The station locations were at NOSC Pier 159 (NOSC, denoted as A in figure 1), at the Harbor Police small boat dock (Harbor Police, denoted as B in figure 1), slip D-62 at the Southwestern Yacht Club (Southwestern, denoted as C in figure 1), and at the outer end of the Silvergate Yacht Club pier (Silvergate, denoted as D in figure 1). At each station, an array measuring 1.00 m x 0.66 m and containing nine plexiglass panels were deployed beneath the dock (figure 4). Each replicate plexiglass panel measured 19.68 cm by 25.40 cm (500 cm^2). The surfaces of these panels were roughed with 120-grit sand paper and then washed with soap and water and thoroughly rinsed with fresh water. They were then attached to the array by plastic ties (figure 4A). Each array was secured with 1.20-cm-diameter nylon line lashed to eyebolts which were placed in the underside of the floating dock (figure 4B-C). The panel arrays were placed under the dock at each station to keep them out of direct sunlight, allow easy access for sampling, and prevent them from interfering with boat traffic (figure 4B-C).

The arrays were placed at the stations on June 17, 1986, and were removed on August 23, 1986. At each station, three panels on each sampling array were removed and replaced after each 3-week exposure period (E in figure 3). The position of panels designated "3 week" in figure 4A were the panels that were removed and replaced after each 3-week exposure period: from June 17 to July 8 (21 days); July 8 to July 29 (21 days); and July 29 to August 23 (26 days). The panels designated "9 week" in figure 4A remained exposed for 9 weeks (D in figure 3).

The organisms living on the panels were sampled according to the following procedure. One side of a panel was randomly selected by coin toss. On the side selected, all the organisms were completely scraped off to obtain a measure of biomass density (g/500 cm^2). Organisms growing on the remaining

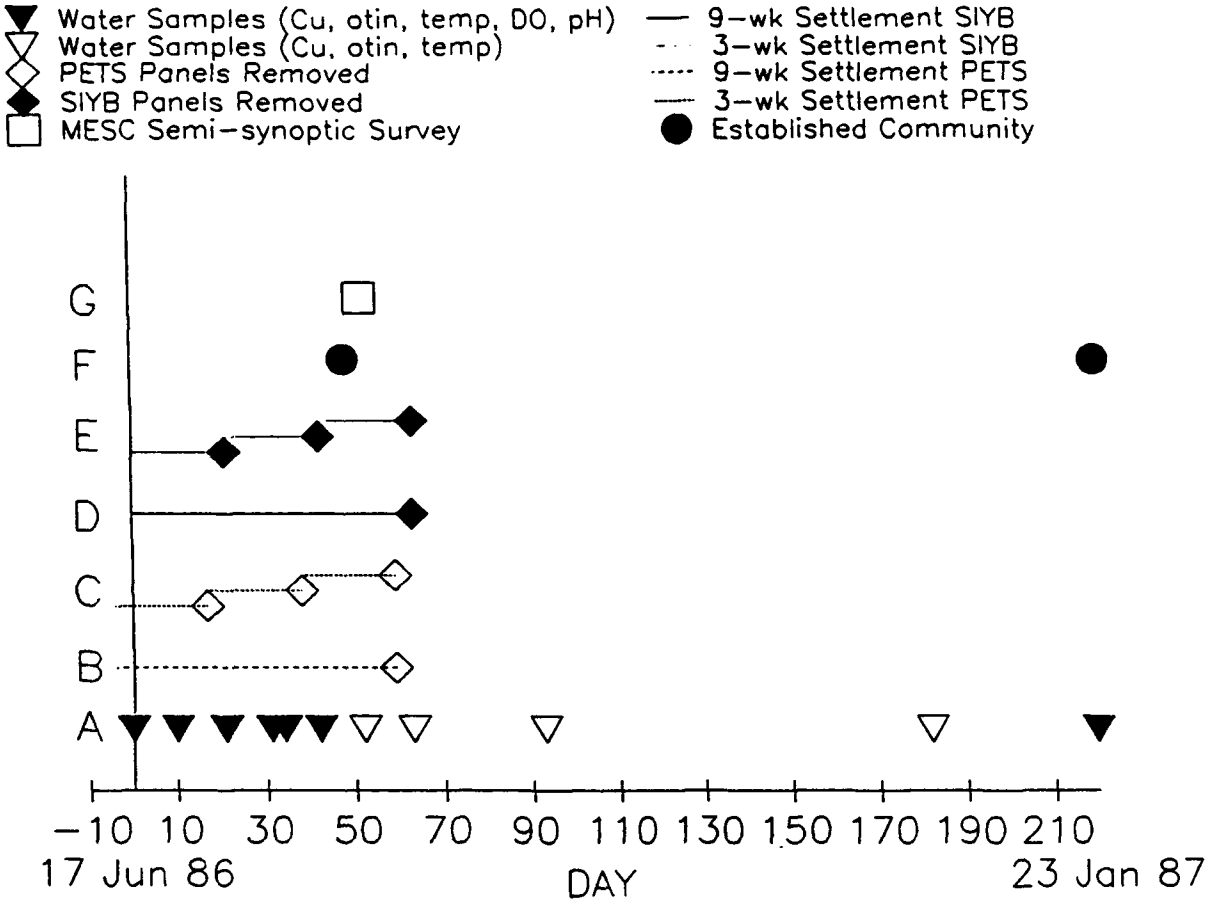


Figure 3. Sequence of sampling events for both field survey and microcosm experiment. Samples were collected for physical and chemical analysis (A). Panels were exposed for 9- and 3-week periods in the Portable Environmental Test System (B and C) and in Shelter Island Yacht Basin (D and E). Established communities were sampled (F) and a semisynoptic survey was performed using the Marine Environmental Survey Craft.

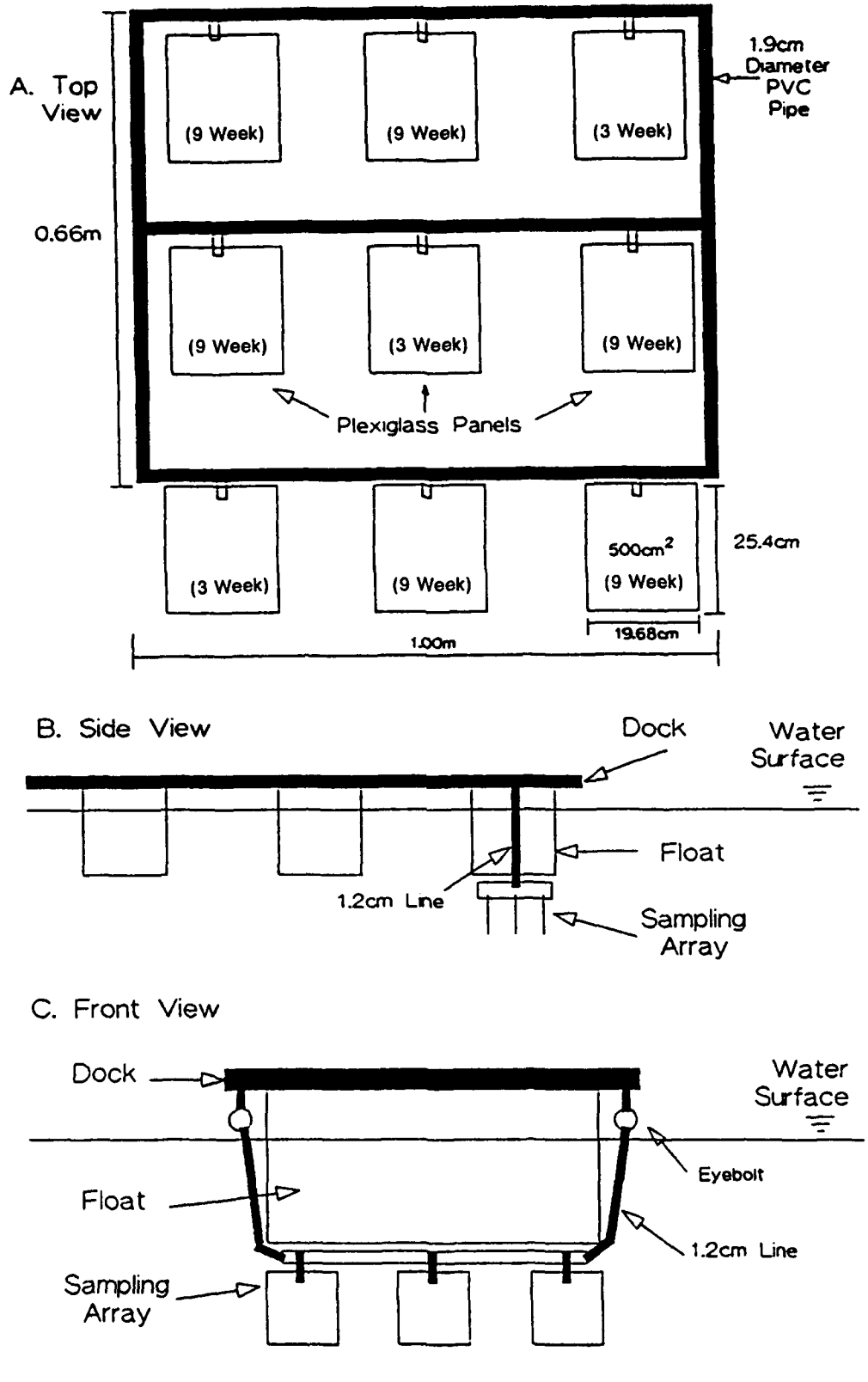


Figure 4. The biological sampling array (A) was deployed beneath floating docks at each station (B). The panels hung vertically, out of sunlight, and away from boat traffic (C).

side were subsampled by dividing the panel from top to bottom into ten 2.54-cm by 19.68-cm (50 cm^2) horizontal strips and randomly selecting one of eight central strips for examination and removal of all organisms contained within it. The top and bottom 2.54-cm-wide strips were not included in this process to avoid edge effects. The organisms were separated and identified to species or lowest possible taxonomic level. Each species or partially identified taxa were placed in separate glass crystalizing dishes of known weight. This biological material was placed in an oven and dried to a constant weight at 100°C for at least 48 h to determine the dry weight biomass (g/50 cm^2) of each species or partially identified taxonomic group.

Dominance-diversity or Whittaker curves were developed from the biological data obtained. Dominance-diversity curves provide a graphical representation of the community structure by depicting the partioning of biomass among the species or taxa present on the panels (Whittaker, 1969; Lambshead et al., 1983). In this case, the dominance-diversity curves were developed by plotting the dry weight biomass (g/50 cm^2), on a logarithm base 10 scale (y-axis), versus the species sequence, or order of taxa from that with the greatest biomass to that with the lowest biomass (x-axis). Specific symbols were used to denote species or taxa present to provide a graphical representation of community composition. Percent biomass was used to allow for relative comparisons among stations. Dominance-diversity curves were constructed for each individual panel and for mean biomass sampled from each station and for each sampling interval.

Biological Data From Established Communities

Established, natural fouling communities were sampled at the Southwestern Yacht Club (Southwestern), Silvergate Yacht Club (Silvergate), and Harbor Police boat dock (Harbor Police) stations on August 10, 1986, (day 54) and at Naval Ocean Systems Center (NOSC), Southwestern, Silvergate, and Harbor Police stations on January 12, 1987, (day 211) to provide data on the naturally occurring fouling community structure during both summer and winter. Samples of established fouling communities collected at the NOSC station on August 15, 1986, were inadvertently removed from freezer storage and thrown away before they could be processed.

The established fouling communities were sampled using SCUBA at the Harbor Police, Southwestern, and Silvergate stations and by using a mask and snorkel at the NOSC station. Two locations were selected on the bottom of fiberglass floats at each station about 1 m beneath the dock and within 1 m of where the array was positioned. Three replicate samples of biological material were obtained at each station by scraping the organisms attached to the fiberglass float into a plastic zip-lock bag. Enough biological material was collected so that each replicate contained approximately the same volume of material.

Qualitative samples were obtained by swimming along an adjacent concrete pier piling from the surface to the bottom and removing the most abundant and or dominant species and placing them in zip-lock plastic bags. On August 10, the fouling communities at the station locations of Southwestern, Silver, and Harbor Police were photographed with an underwater camera.

The qualitative samples were preserved by anesthetizing the organisms in an isotonic MgCl solution and placing them in a 10% solution of formalin in seawater (Smith and Carlton, 1975).

The quantitative samples from the quadrats were either analyzed fresh or were preserved by freezing and later thawed for analysis. The material from each replicate was subsampled three times by transferring enough material to fill a 10-cm by 12-cm plastic sorting tray with sides 1.27 cm high (120 cm^2). The sorting tray was divided into 12 equal squares of 10 cm^2 each. Three of these squares (30 cm^2) were selected by random draw, and all the biological material contained within the selected

squares were sorted and identified to species or to lowest taxonomic level possible. When individual organisms or colonies of individuals overlapped the selected squares, a scalpel was used to slice the organism(s) along the boundary between the adjoining squares. The sorted material for each taxon was transferred into separate glass crystalizing dishes of known weight. The material was dried to a constant weight at 100°C for at least 48 h and reweighed to determine dry weight biomass per 90 cm^2 of each species or taxonomic group for each replicate quadrat.

Water Quality Monitoring

In order to characterize the water quality gradient present in Shelter Island Yacht Basin, water samples for chemical analysis of copper and organotin compounds were collected at the four monitoring stations in Shelter Island Yacht Basin (figure 1). The sampling dates were June 17 (day 0), June 27 (day 10), July 8 (day 21), July 18 (day 31), July 22 (day 34), July 29 (day 42), August 8 (day 52), August 19 (day 63), October 21 (day 93), November 18, 1986 (day 180), and January 23, 1987 (day 220) (A in figure 3). These data were also used to provide a measure of variability in environmental conditions over the study period. Predicted tides for San Diego Bay from June 17 to August 19, 1986, (figure 5A) were used to select sampling days. Predicted tides for each sampling day were used to select water samples which corresponded to high, mid, and low tidal states (figures 5B-I). Predicted tides were generated using the Tide Prediction Program, version 2.0a (Marine Computer Systems Incorporated, 1986).

On days 0, 10, 21, 31, 52, 63, 93, and 182, three water samples were taken at each station at each of the times corresponding to high, mid, and low tide (figure 5B-I). On days 42 and 220, samples were taken only at high and low water, while on day 34 samples were only collected at low tide. Samples for copper analysis were not taken on day 93. Water samples were taken at a depth of about 50 cm below the surface in an area immediately adjacent (within 2 m) to the fouling panel array.

At each station, a sample for organotin hydride analysis was collected in either a 1000-ml or 500-ml polycarbonate bottle. All polycarbonate bottles used were new. Also, two 250-ml samples were taken for copper analysis using polyethylene bottles. These bottles had been washed with laboratory soap and then rinsed thoroughly with 18 ohm de-ionized water, filled with 0.1 N HCl wash acid, and allowed to stand for at least 24 h. The acid wash was removed prior to field sampling.

At the time of sampling, each bottle was labeled and rinsed three times with seawater at the sampling site by inverting and removing the cap approximately 50 cm below the surface to avoid contamination with oils and scum on the surface. The organotin samples were frozen until analysis using hydride generation and atomic absorption detection to determine the concentrations of tributyltin (TBT), dibutyltin (DBT), and monobutyltin (MBT) compounds (Stang, 1985; Valkirs et al., 1986; Stallard et al., 1989). The accuracy of this method was ±15% of the mean standard concentration, with a coefficient of variation of 6% and a detection limit of 0.005 µg/l (Valkirs et al., 1985b; Stallard et al., 1989; P. M. Stang, Computer Sciences Corporation, personal communication).

Within 1 h of sampling, the copper samples were acidified to 1.8 pH by adding 1 ml concentrated HCl. The samples were kept in a dark box until they were analyzed by anodic stripping voltammetry (ASV) for labile copper (cupric ion) activity (Zirino, 1981; Johnston et al., 1986) and inductively coupled plasma atomic emission spectroscopy (ICP) for total copper concentrations. The ASV measurements were made with a hanging mercury drop electrode using a BAS 100 analyzer. The accuracy of the ASV and ICP methods were determined by analysis of standard curves. The ASV method was accurate within ±20% of the mean standard concentration with a detection limit of 0.6 µg/l. The ICP samples were measured directly with a J-Y 38 analyzer. The ICP method was accurate within ±15%

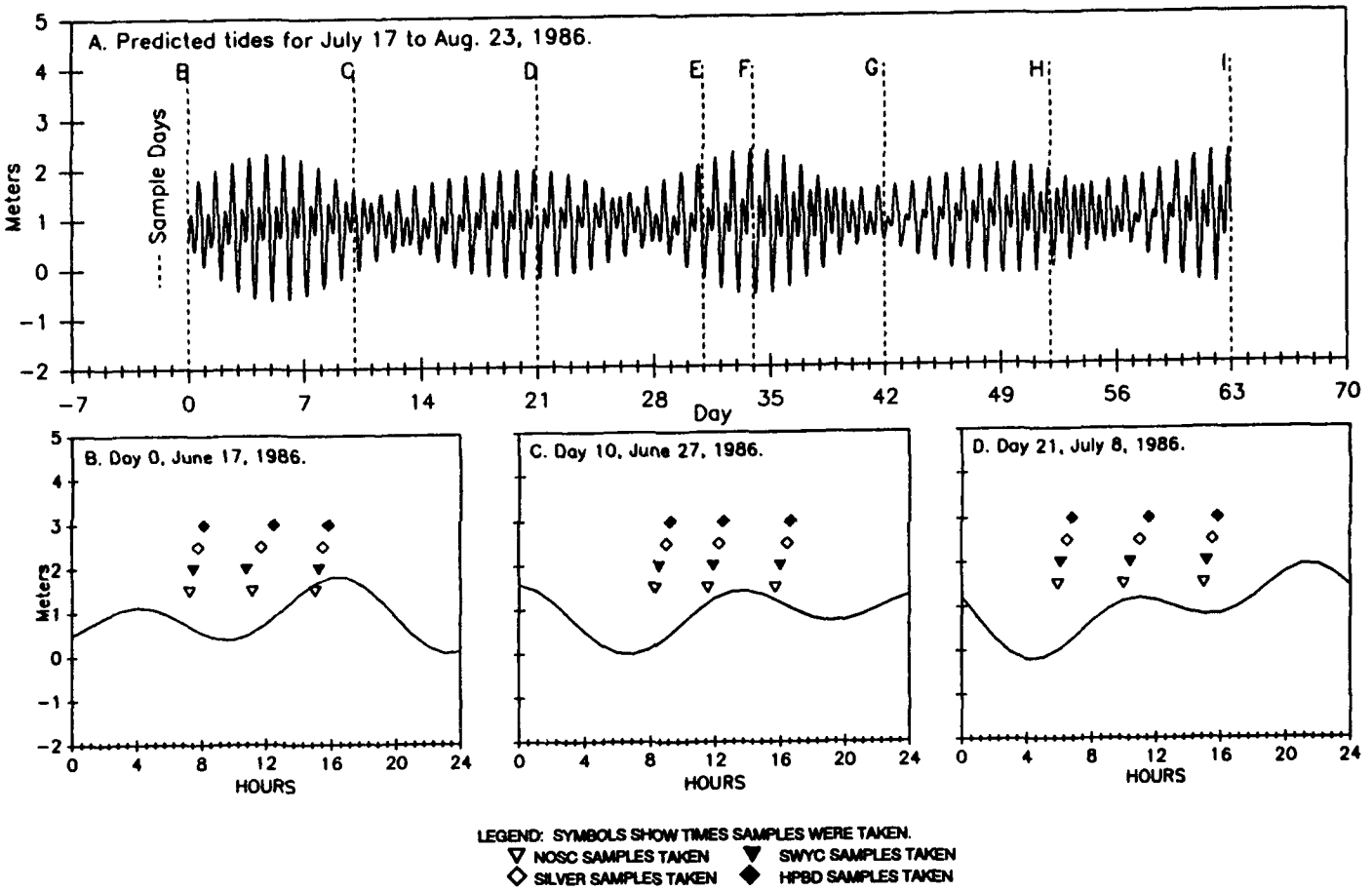


Figure 5. Predicted tide heights in San Diego Bay from June 17 (Day 0) to August 19,1986 (Day 63) (A). Predicted tides for each sampling day are shown in B-I.

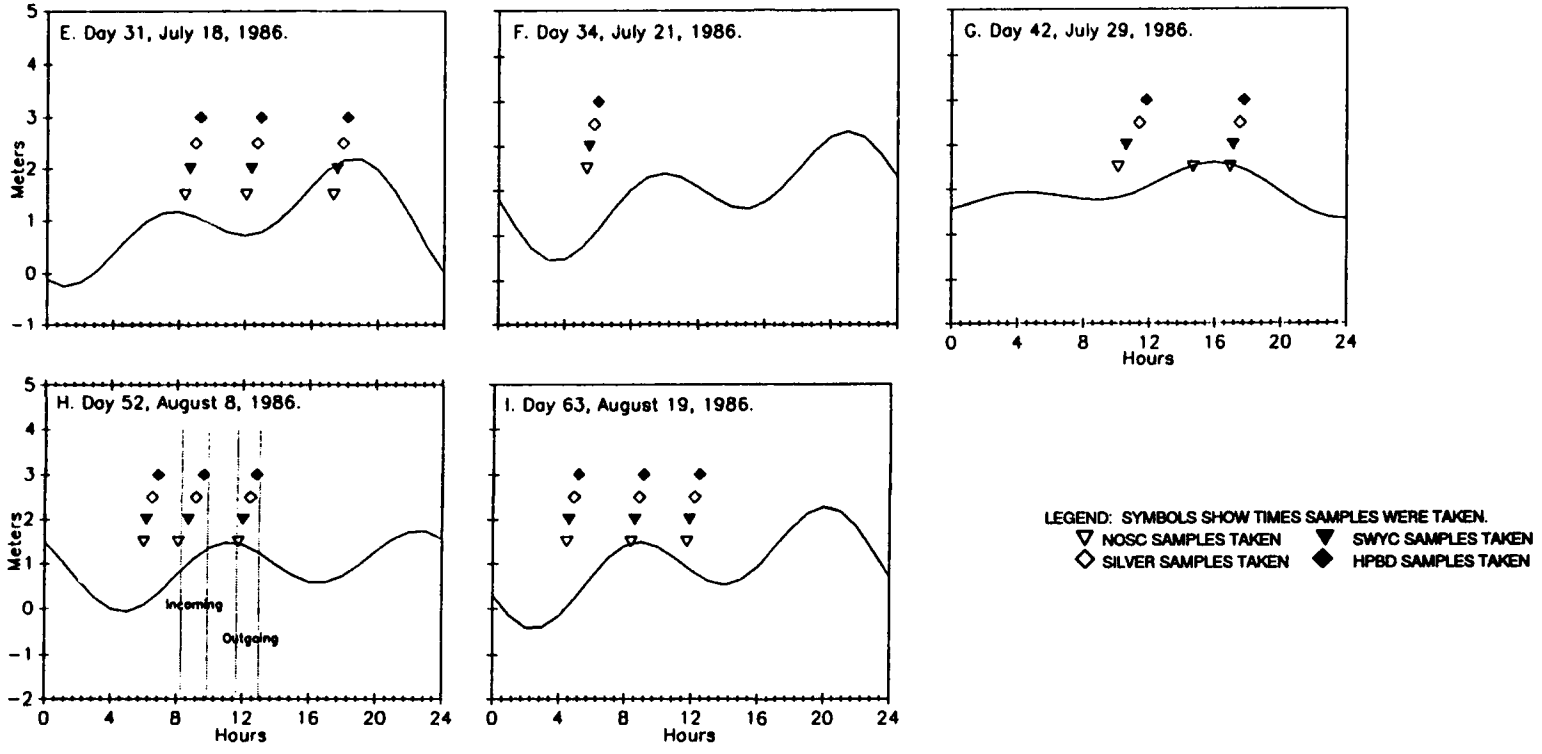


Figure 5. Continued.

of the mean standard concentration with a detection limit of 2.0 µg/l (R. Fuhrmann, NOSC, personal communication).

At the same time the water samples were taken, temperature, dissolved oxygen, and pH were measured using a Horiba Water Checker. The Horiba Water Checker measured temperature with a thermistor (accurate to within ±0.5°C), pH with a glass electrode (accurate to within ±0.1 pH), and dissolved oxygen with a membrane galvanic cell (accurate to within ±1.0 mg/l) (Horiba Instruments Incorporated, 1978). The Horiba sampler was periodically calibrated during the study, following the manufacturer's instructions. The calibration procedures compared the Horiba readings with a glass thermometer for temperature and with 4.5 pH and 7.0 pH buffer solutions for pH.

On occasions when the Horiba sampler was not available, temperature was recorded using a glass thermometer. Dissolved oxygen and pH were not measured on days 0, 52, 63, or 182. Temperature was not measured on day 0.

Semisynoptic Horizontal Survey

On August 8, 1986 (day 52 of the field study described above), a semisynoptic horizontal survey of physical and chemical characteristics of the Shelter Island Yacht Basin was made using the Marine Environmental Survey Craft (MESC). The MESC system is a self-contained floating laboratory capable of making continuous measurements of environmental variables as the vessel traverses the sampling area (Zirino and Johnston, 1984; Bower and Lieberman, 1985; Lieberman et al., 1985; Johnston et al., 1986). The survey was performed during an incoming and an outgoing tide to obtain information on gradients of temperature, salinity, dissolved oxygen, turbidity, pH, chlorophyll, and cupric ion activity in Shelter Island Yacht Basin during changing tide.

The MESC system was equipped with a Motorola Falcon 484 positioning system which was capable of determining the position of the MESC within ±3 m. The positioning information, consisting of (x,y) coordinates, was entered automatically into the data acquisition system. The data acquisition system also recorded data collected from water quality sensors maintained on board the MESC. The sensors used and their precision are listed in table 1.

Table 1. The sensors used and sensor precision for variables measured with the Marine Environmental Survey Craft.

Variable	Instrument	Precision [a]
Temperature	InterOceans 513D CTD	±0.01 °C
Salinity	InterOceans 513D CTD	±0.05 °/oo
Dissolved O_2	InterOceans 513D CTD	±0.05 mg/L
Transmittance	InterOceans 513D CTD	±10% at 1V
Bottom Depth	Interspace Tech. Fathometer	±0.1 m
Relative Cu^{2+}	AgCl reference electrode #1	±2% at -100 mV
Relative Cu^{2+}	AgCl reference electrode #2	±2% at -100 mV
pH	Corning glass electrode	±0.01 pH
Chlorophyll a	Turner Designs Fluorometer with flowthrough attachment	±5% at 10 mV

[a]The ability of the sensor to distinguish differences.

Temperature, salinity, dissolved oxygen, and relative transmittance were measured in situ with a conductivity, temperature, depth (CTD) probe towed 1.3 m below the surface. A Jabsco Model 18630-003 sealless magnetic pump was used to pump seawater from an inlet on the CTD through

approximately 5 m of noncontaminating polyethylene hose through a manifold containing flowthrough sensors. The sensors included a glass electrode to measure pH, a fluorometer to measure chlorophyll a fluorescence, and two ion-specific electrodes to measure cupric ion activity. The data measured in situ and flowthrough were combined with bottom depth and recorded continuously at 2-second intervals as the MESC traversed the sampling area during incoming (0817 to 0954 h) and outgoing (1139 to 1300 h) tidal conditions.

The MESC sampling operations in relation to the predicted tides for August 8, 1986 (day 52), are shown in figure 5H. Analyses were performed on a subset of the data consisting of every tenth sample. At an average speed of 3.7 km/h (1.03 m/s) a sample every 20 s corresponds to a sample every 20.6 m. Samples for organotin and copper analyses were taken at the four locations of the Shelter Island biological and chemical sampling stations as previously described (figure 5H).

In order to quantify the gradients of the water quality variables measured in the yacht basin, the (x,y) positioning data were used to determine within which of five areas of the yacht basin the samples were taken. The designated areas of the yacht basin were identified as Naval Ocean Systems Center (nosc), Harbor Police boat dock (hpbd), Southwestern Yacht Club (swyc), Silvergate Yacht Club (silver), and La Playa inlet (laplaya) (figure 6). The (x,y) positioning data were also used to calculate the distance, in relative units, from the main channel at which each sample was taken.

Time series plots of the data obtained from the transects during incoming and outgoing tides were developed to show the variability of the water quality variables within the yacht basin. Descriptive statistics and analysis of variance were used to evaluate differences in the water quality gradient between the designated areas of the yacht basin. Correlations of data for temperature, salinity, dissolved oxygen, transmittance, bottom depth, pH, ion specific electrode response, chlorophyll a fluorescence, and distance from main channel were computed for data obtained during incoming tide, outgoing tide, and both incoming and outgoing tides combined to evaluate the variability of the water quality data between areas of the yacht basin.

Statistical Analysis

Field survey data. Analysis of variance (ANOVA) was applied to data for tributyltin, dibutyltin, monobutyltin, copper by ASV, copper by ICP, temperature, dissolved oxygen, pH, and salinity to determine if there were significant differences between the average concentrations of pollutants at the stations.

Logarithmic transformations ($\log_{10}$) were applied to the ASV, ICP, MBT, DBT, and TBT data. Means, confidence intervals, and analysis of variance were calculated using the transformed data. The means were calculated using the following formula:

$$\overline{C}_i = antilog \left\{ \left[\sum_{j=1}^{9} \left(\sum_{k=1}^{3} log\ C_{ijk} \right) /3 \right] /9 \right\}$$

Where $\overline{C}_i$ is the mean concentration at station i, j is the number of sampling days, and k is the number of tide states samples were taken.

The 95 percentile confidence intervals for the mean of each variable were calculated from the mean sum of squares (SS_m) obtained for each station:

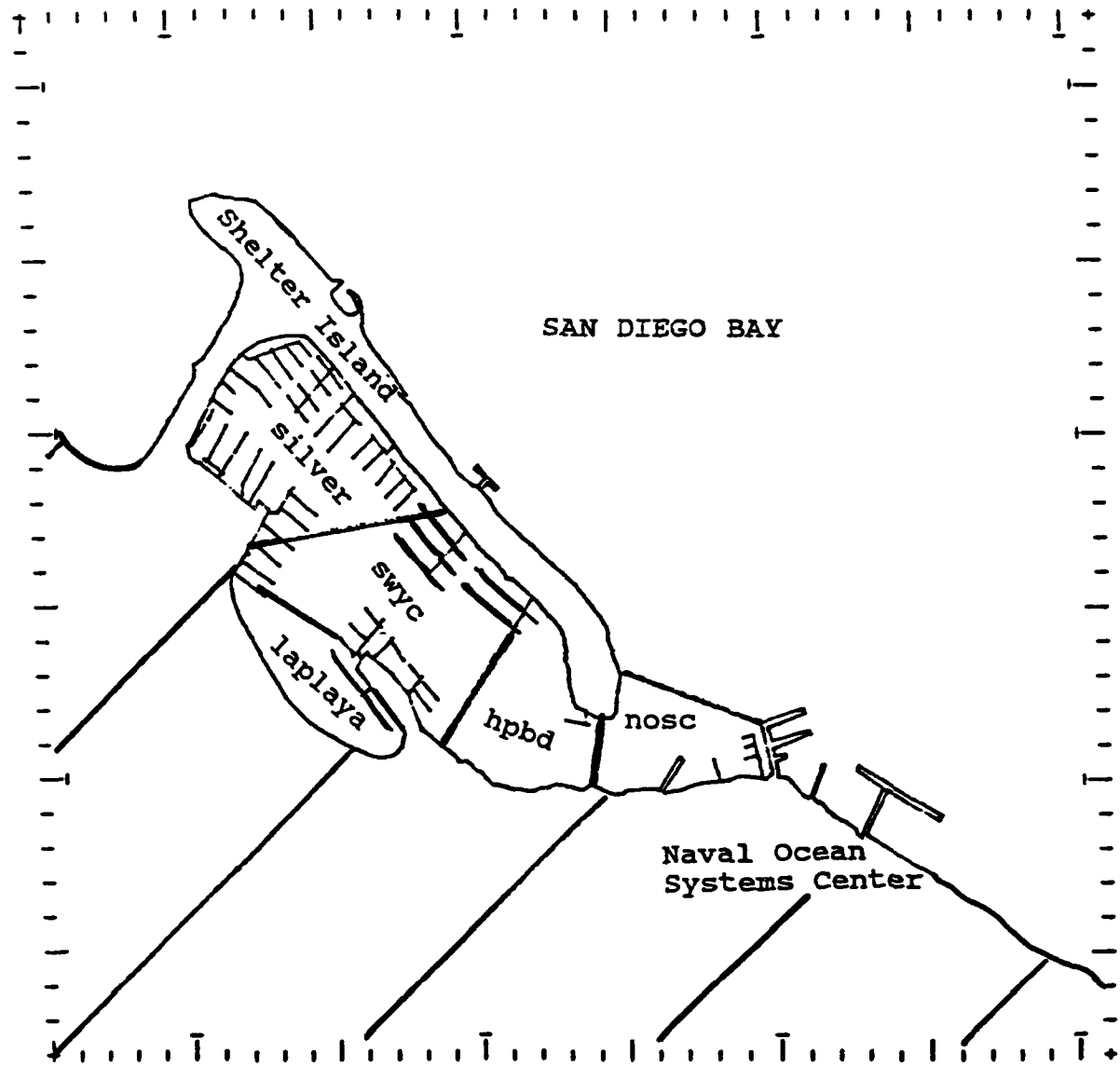


Figure 6. Areas in Shelter Island Yacht Basin used for the analysis of the MESC data.

SD = standard deviation = $(SS_m/(n-1))^{1/2}$ where n = number of samples,

SE = standard error = $SD/(n)^{1/2}$

CI = confidence interval = $\bar{X} \pm (t_{.05[df]})SE$

Where t was the critical value of the t-distribution with df degrees of freedom. The reverse transform of $x = 10^{x'}$ was then applied to the means and confidence intervals to determine the 95% confidence intervals in the original units.

A split-plot model was used to evaluate the variance components contributed by station, day, tide, and their respective interactions (Snedecor and Cochran, 1980, p 325). The ANOVA was calculated using the microcomputer program STATISTIX (NH Analytical, 1986) where station was the main treatment, day was the major blocking factor, and tidal state was the subtreatment. The interaction term between station and day was used as the error term to detect station effects, and the interaction between station and tide was used to detect tide effects. The blocking factor is DAY, which has four main treatments of STATION which has three subtreatments, TIDE (figure 7) (Snedecor and Cochran, 1980, p 326; Sokal and Rohlf, 1981).

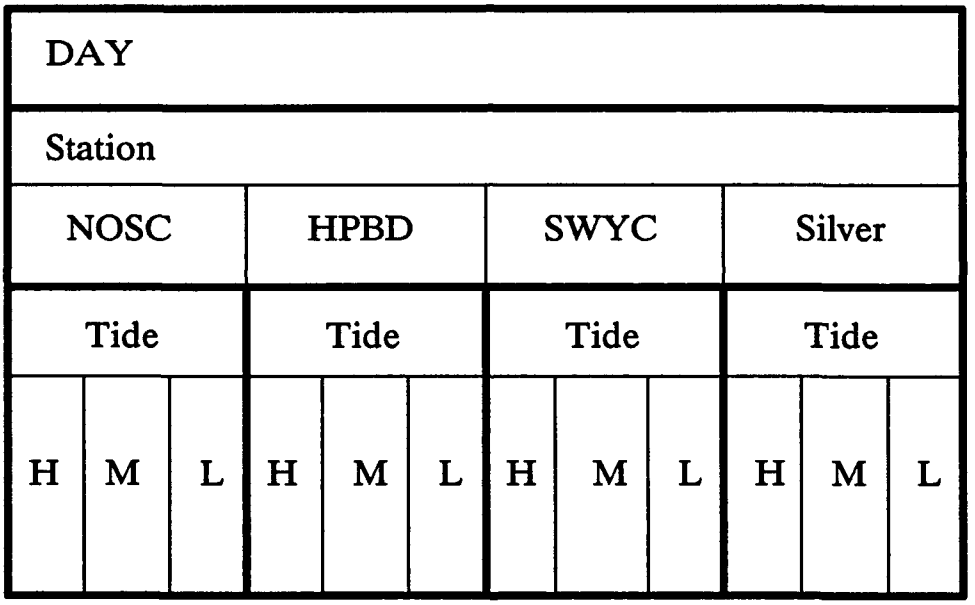


Figure 7. Graphical representation of the ANOVA for water chemistry data. The blocking factor was DAY, which had four treatments—STATION, which had three subtreatments—TIDE.

To account for missing data points noted above and the resulting unequal sample sizes, only a subset of the data was used in the ANOVA model. Table 2 shows the data and the transformations used for the ANOVA. The data collected at low tide on day 34 were used as an additional replicate for day 42 to provide a balanced model of one sample for each tide state for each station. The null hypothesis tested by the F test of each ANOVA was that all mean values were equal.

Table 2. The variables, transformation to obtain normality, and the subset of data used for the ANOVA of physical and chemical data collected in Shelter Island Yacht Basin.

Variable	Transform	Data Used in ANOVA (Day)
Copper (ASV)	log(ASV)	0, 10, 21, 31, 42, 52, 63, 182
Copper (ICP)	log(ICP)	0, 10, 21, 31, 42, 52, 63, 182
Monobutyltin (MBT)	log(MBT)	0, 10, 21, 31, 42, 52, 63, 93, 182
Dibutyltin (DBT)	log(DBT)	0, 10, 21, 31, 42, 52, 63, 93, 182
Tributyltin (MBT)	log(TBT)	0, 10, 21, 31, 42, 52, 63, 93, 182
Temperature (TEMP)	none	10, 21, 31, 42, 182
pH	none	10, 21, 31, 42
Dissolved O_2 (DO)	none	10, 21, 31, 42

Relationships between the physical-chemical and biological variables. The relationship between the pollution gradient and the biological data for groups of taxa was evaluated using multiple linear regression (MLR) and correlation analyses. The settlement and colonization variables used were obtained from the panels and consisted of the number of species per panel, dry weight biomass density obtained from scraping one side of each panel, and the dry weight biomass obtained for each of the following taxa taken from the remaining side of the panels: bryozoans, tunicates, polychaetes, and all other species (mostly sponges and amphipods). These groups were selected based on their taxonomic similarities and relative abundance on the panels.

The data collected from the 3-week and 9-week sampling intervals were analyzed separately. The physical-chemical data used in the regression analysis consisted of the mean concentration of toxic chemicals measured at each station while the panels were exposed. Each panel represented a replicate measure of settlement and colonization under those conditions.

The biological data were transformed using a logarithmic transformation ($\log_{10}$). A constant weight of 0.0001 g/50 cm^2, the lowest possible biomass measurement, was added to each variable to allow log transformations of variables with zero biomass (table 3).

A one-way analysis of variance was used for the 9-week biological data to determine if there were differences between stations. A two-way analysis of variance was used for the 3-week biological data to determine if there were differences between stations as well as differences within stations for each sampling period (Snedecor and Cochran, 1980; Sokal and Rohlf, 1981).

Correlation coefficients (Pearson Product Moment) were calculated between the biological variables obtained from panels exposed for 3-week and 9-week intervals and the mean physical and chemical data obtained during the exposure intervals. The correlation coefficients between the physical and chemical data were calculated from all the field monitoring data (table 2). The null hypothesis tested by the correlation analysis was that the sample correlation coefficients were obtained from a population with a parametric correlation coefficient of zero.

Table 3. The transformations applied to the biological data from panels exposed for 9-week (A) and 3-week (B) periods. The transformed data were used for the ANOVA, correlation analysis, multiple regression, and principal component analysis.

(A) Data from 9-week panels.

Variable	Units	Symbol	Transformation
Species richness	spp/50 cm²	SPP	none
Biomass density	g/500 cm²	BIO	log(BIO+.0001)
Polychaete biomass	g/50 cm²	POLY	log(POLY+.0001)
Bryozoan biomass	g/50 cm²	BRY	log(BRY+.0001)
Ascidian biomass	g/50 cm²	ASC	log(ASC+.0001)
Other spp. biomass	g/50 cm²	OTH	log(OTH+.0001)

(B) Data from 3-week panels.

Variable	Units	Symbol	Transformation
Species richness	spp/50 cm²	SPP	none
Biomass density	g/500 cm²	BIO	log(BIO+.0001)
Polychaete biomass	g/50 cm²	POLY	log(POLY+.0001)
Bryozoan biomass	g/50 cm²	BRY	log(BRY+.0001)
Ascidian biomass	g/50 cm²	ASC	log(ASC+.0001)

Multiple regression was performed to determine if there were linear relationships between the biological abundance (dependent) and physical chemical (independent) variables. The regression model used had the form

$$Y_n = a + bX_1 + cX_2 + dX_3 + \ldots + zX_n$$

where Y_n = dependent variable, $X_1, X_2, X_3, \cdots x_n$ = independent variables used, and $a, b, c, \ldots z$ = the regression coefficients (table 4).

Table 4. The variables used for regression between biological and physical-chemical variables.

Dependent (Y_n) Settlement Data		Independent ($X_1X_2X_3 \ldots X_n$) Physical-Chemical Data
Species richness	(spp./panel)	Mean TBT (µg/l)
Biomass density	(g/500 cm²)	Mean DBT (µg/l)
Polychaete biomass	(g/50 cm²)	Mean MBT (µg/l)
Bryozoan biomass	(g/50 cm²)	Mean ASV (µg/l)
Tunicate biomass	(g/50 cm²)	Mean ICP (µg/l)
Other-spp. biomass	(g/50 cm²)	Mean Temp (°C)
		Mean pH
		Mean DO (µg/l)

Principal component analysis was applied to the biological and physical chemical data to evaluate the ability of linear combinations of the physical chemical data to predict the biological data. Principal components were calculated using the microcomputer statistical program STATISTIX for subsets of the independent data. The subsets used were the toxic chemical variables (TBT, DBT, MBT, ASV, and ICP), the physical variables (TEMP, PH, and DO), and the environmental variables, which consisted of both the toxic chemical and physical variables. The first eigenvector obtained from each subset was used in regression analysis of the dependent biological variables. Plots of the first principal components versus the dependent variables were generated to graphically depict the ability of the eigenvectors to predict the dependent variables.

MICROCOSM EXPERIMENT

The microcosm study was conducted from June 13 to August 15, 1986, during phase 1 of the test and evaluation of the portable environmental test system (PETS) described in Salazar et al. (1987a, 1987b). During the PETS test and evaluation, 12 microcosm tanks (1.00 m × 0.66 m × 0.66 m deep), each containing 340 l of San Diego Bay water, were maintained at the Environmental Ordnance Disposal-Mobile Unit 3 (EOD-MU3) pier located at the Naval Amphibious Base, Coronado, California (figure 1). The microcosm system provided continuous flowthrough seawater to each tank at a rate of 3.6 l/min, resulting in an average residence time of 1.5 h for water in the microcosm tanks (Salazar et al., 1987a, 1987b).

Tributyltin (TBT) was introduced into the tanks by exposing unfiltered San Diego Bay water to surfaces coated with paint containing organotin (International Paint Co., BFA 956 Pink SPC-9 HiSol) in a separate 1000-l leachate tank. The flow rate through the leachate tank was 3.6 l/min, with an average water residence time of 4.6 h. This resulted in an average concentration of 0.2 µg/l TBT in the leachate water (Salazar et al., 1987a). The leachate water was diluted with unfiltered ambient bay water to obtain the treatment concentrations, which then flowed directly into three replicate microcosm tanks per treatment. The percentage of leachate water and the resulting mean and standard deviation of TBT concentrations in the microcosm tanks were measured as follows: 100% leachate was 0.204 ± 0.070 µg/l TBT, 25% leachate was 0.092 ± 0.044 µg/l TBT, and 10% leachate was 0.079 ± 0.041 µg/l TBT. Unfiltered ambient seawater was supplied to three control tanks. The mean and standard deviation of the ambient TBT concentration, measured in the bay, was 0.006 ± 0.006 µg/l (Salazar et al., 1987a).

Three settling panels of exactly the same type used in the field study at the Shelter Island Yacht
were placed in each replicate tank on June 13, 1986 (day 0 of microcosm study). Two of the panels remained in the microcosm tanks until August 15, 1986 (day 63). The other panel was removed and replaced with a new panel after 3 weeks of exposure, on July 4 (day 21) and July 25 (day 42) and removed on August 15 (day 63), to provide separate measures of recruitment over 3-week intervals.

In addition, nine panels were placed in the bay under a floating dock adjacent to the seawater intake lines used to supply the microcosm system. Six of these panels remained exposed for the 9-week duration of the study. The remaining three panels were removed and replaced at the same times as the microcosm panels to obtain measures of recruitment during 3-week intervals. The panels from the microcosm and dock were analyzed using exactly the same procedures employed for the panels sampled during the field study at the Shelter Island Yacht Basin, as described above. The concentration of TBT and the temperature, conductivity, pH, and dissolved oxygen in the microcosm tanks were determined twice per week during the study period. The results of these measurements are reported in Salazar et al. (1987a, 1987b).

RESULTS

FIELD SURVEY

Physical and Chemical Data

Means and results of analysis of variance (ANOVA) for physical and chemical data collected from Shelter Island Yacht Basin showed highly significant differences ($p<0.001$) between stations for copper determined by anodic stripping voltammetery (ASV), copper determined by inductively coupled plasma spectroscopy (ICP), and the organotin compounds tributyltin (TBT), dibutyltin (DBT), and monobutyltin (MBT) (table 5). Significant differences between days were also detected for copper ASV, DBT, MBT, temperature, pH, and dissolved oxygen (table 5).

Table 5. Variations in physical and chemical variables along pollution gradient in Shelter Island Yacht Basin. (A) Means and results from analysis of variance, and (B) correlation matrix for physical and chemical data.

(A)		mean concn. (µg/l) or value				ANOVA[c]		
Variable[a]	n[b]	NOSC	HPBD	SWYC	SILVER	STA	DAY	TIDE
ASV	24	2.63	7.08	8.91	11.07	***	***	*
ICP	24	5.13	6.46	11.48	11.75	***	+	+
TBT	24	0.04	0.21	0.27	0.35	***	**	NS
DBT	24	0.03	0.17	0.22	0.32	***	***	*
MBT	24	0.02	0.06	0.08	0.09	***	***	*
TEMP	15	19.36	20.27	20.15	20.69	*	***	NS
pH	12	7.46	7.34	7.38	7.35	NS	***	NS
DO	12	7.43	7.81	7.66	7.35	NS	***	*

(B) Correlation matrix.

	TBT	DBT	MBT	ASV	ICP	TEMP	pH
DBT	0.85**						
MBT	0.61**	0.69**					
ASV	0.63**	0.67**	0.53**				
ICP	0.62**	0.74**	0.60**	0.75**			
TEMP	0.33	0.26	0.41*	0.29	0.32		
pH	0.23	0.26	0.20	0.21	0.13	-0.30	
DO	-0.22	-0.23	-0.11	-0.27	-0.14	-0.03	-0.64

[a] full variable names are listed in table 2.
[b] n represents number of days × number of tidal levels (3)
[c] significant levels denoted as:

*** = $p \leq 0.001$
** = $0.01 \geq p > 0.001$
* = $0.05 \geq p > 0.01$
+ = $0.15 \geq p > 0.05$

Mean concentrations of copper ASV were lowest at the Naval Ocean Systems Center (NOSC) station and increased by a factor of 4.2 to the highest station at Silvergate Yacht Club (Silvergate) (table 5). Mean concentrations of copper ICP and the butyltins TBT, DBT, and MBT were also lower at the NOSC station and highest at the Silvergate station. The gradient was composed of copper ICP concentrations which increased by a factor of 2.3, TBT concentrations increased by a factor of 8.7, DBT concentrations increased by a factor of 10.1, and MBT concentrations increased by a factor of 4.5 between the outermost and innermost station.

There were only slight and marginally significant differences ($0.15 \geq p \leq 0.05$) between the stations for temperature. Differences between stations for pH and dissolved oxygen were not statistically significant ($p>0.15$). The ANOVA showed there were distinctly different concentrations of toxic chemical concentrations measured between the stations and only slight differences in the physical variables measured between the stations.

Copper data. Concentrations of copper ASV were more variable than copper ICP for the Harbor Police, Southwestern Yacht Club (Southwestern), and Silvergate stations, but were about equal to the variability of copper ICP at the NOSC station (figure 8A). The slight differences in the mean values obtained for copper ASV and ICP (table 5) suggest that most of the copper was present in labile form, except for the copper at the NOSC station, where there were consistently higher concentrations of the total copper measured by ICP (figure 8A).

The concentrations of copper ASV and copper ICP were consistently lower at the NOSC station than at the stations located farther inside the yacht basin (figures 9 and 10). The variance among days obtained for the copper ASV data showed that the data collected at the Harbor Police station was almost three times more variable than the data from the Southwestern or Silvergate stations and twice as variable as the data from the NOSC station. The highest variance among tides occurred during spring tide (day 31) while the lowest tidal variance was measured during neap tide (day 10).

The highest variance among days for the copper ICP data was obtained for the data collected at the NOSC station which was 1.2, 2.5, and 4 times higher than the daily variance in the data from the Harbor Police, Silvergate, and Southwestern stations, respectively. The highest tidal variance in the copper ICP data also occurred during spring tide (day 31), and the lowest tidal variance was measure during neap tide (day 42).

Comparisons of copper concentrations determined by anodic stripping voltammetry (ASV) and inductively coupled plasma atomic emission spectroscopy (ICP) were performed to compare the relative differences in copper speciation between the stations, provide a quality assurance measure between the two methods, and investigate the performance of the methods on samples from the Shelter Island Yacht Basin. Because most of the ASV samples were analyzed 2 to 3 months before the ICP samples were analyzed, water samples were collected and analyzed on the same day (September 17, 1987) to determine if there were differences between the methods. The data were evaluated by regression analysis. The results showed almost a direct one-to-one correspondence of the copper determined using ASV and ICP (figure 11).

Regression analysis was performed on all the ICP and ASV data collected between June 17, 1986, and September 17, 1987, to evaluate the relationship of total copper to labile copper in Shelter Island Yacht Basin. For this analysis all ASV values over 2.5×10^{-7} M Cu (15 µg/l) were omitted from the regression (figure 12). These values were omitted because the concentration of copper exceeded the equilibrium potential of the ASV method (Zirino and Lieberman, 1975; Zirino, 1981; A. Zirino, NOSC, personal communication). The ASV and ICP data below 2.5×10^{-7} M Cu (15 µg/l) were directly related indicating that the most of the copper was probably in labile form. A significant

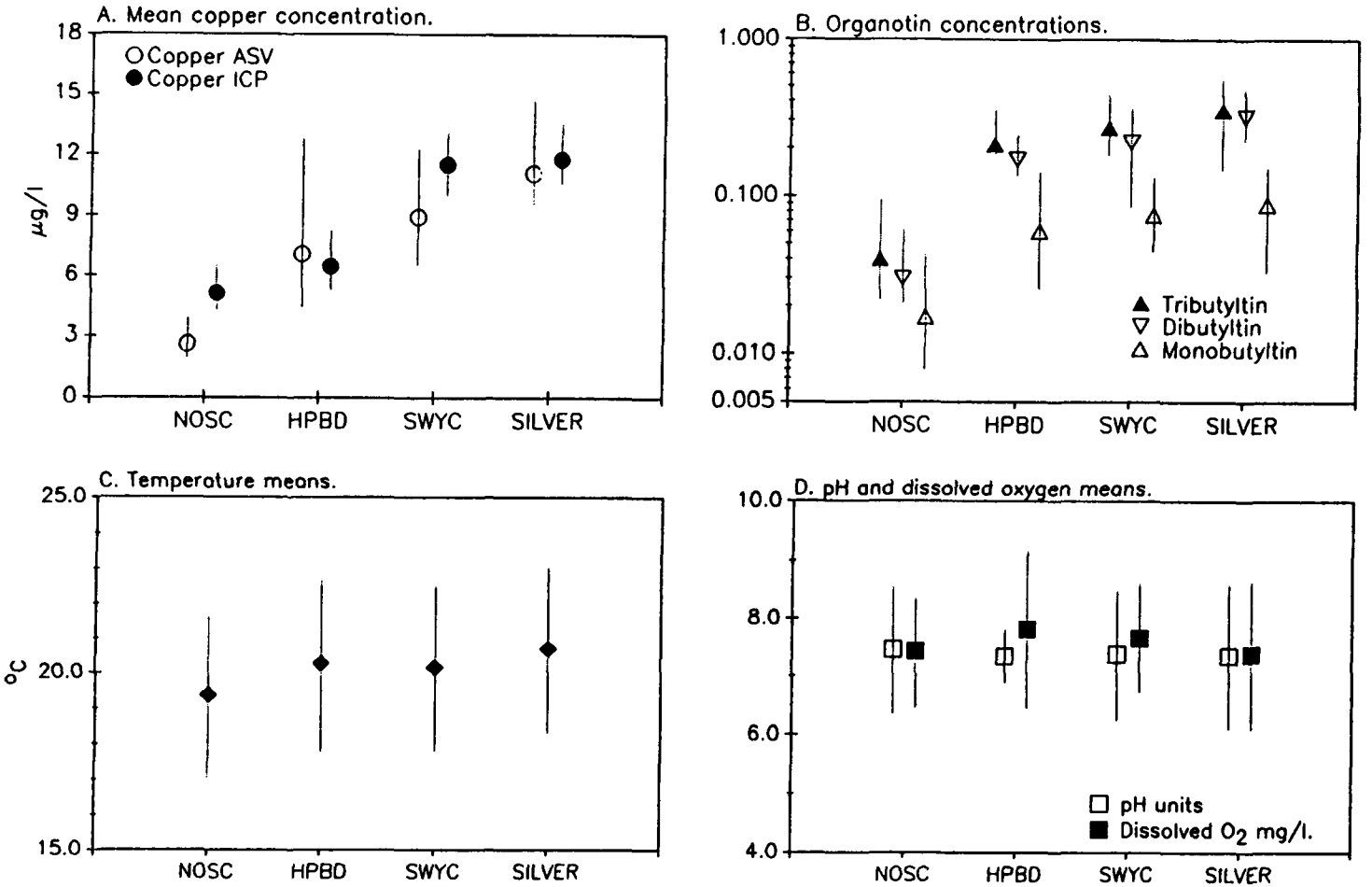


Figure 8. Means and 95% confidence intervals for physical and chemical data.

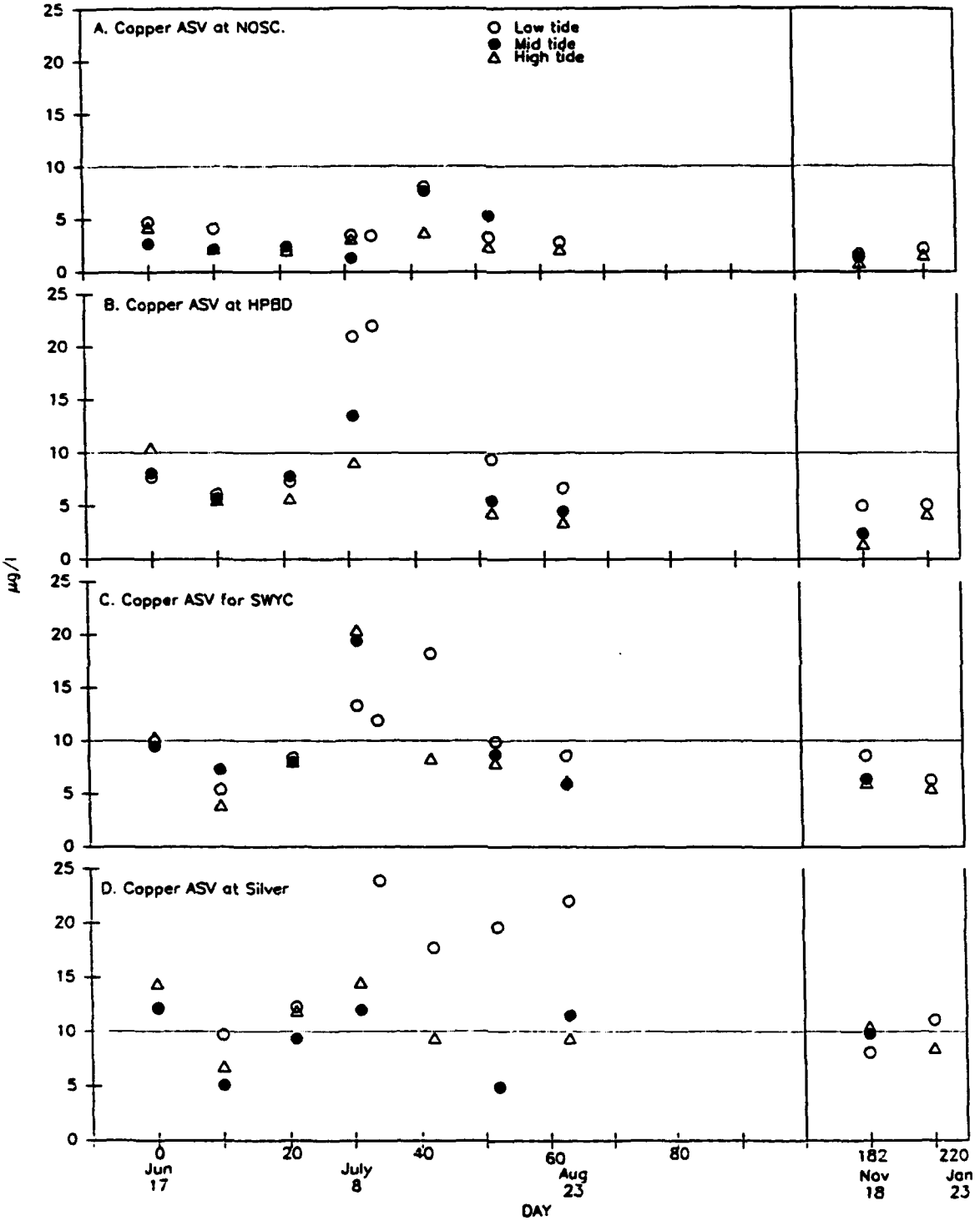


Figure 9. Copper determined by anodic stripping voltammetry (ASV).

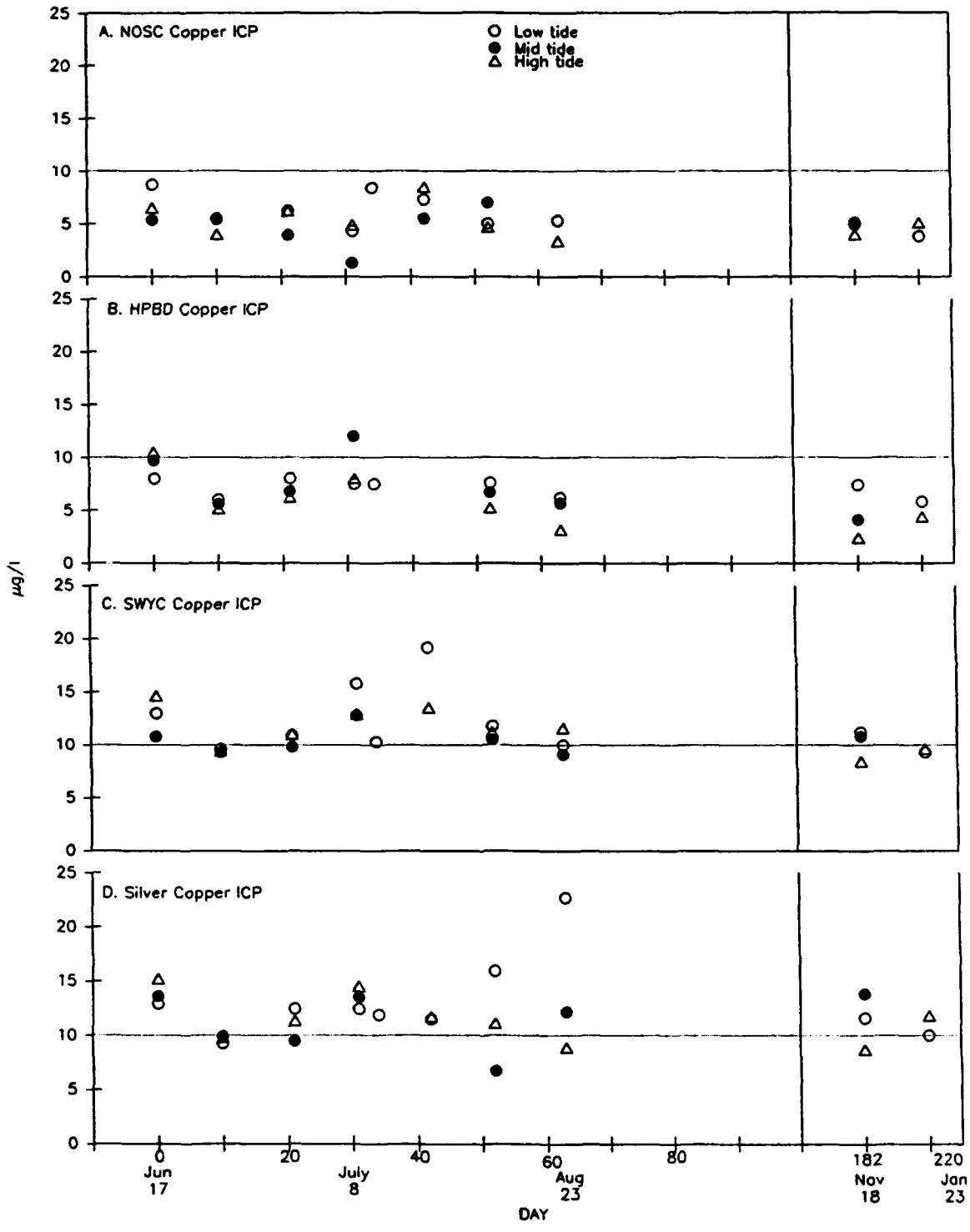


Figure 10. Copper determined by inductively coupled plasma spectroscopy (ICP).

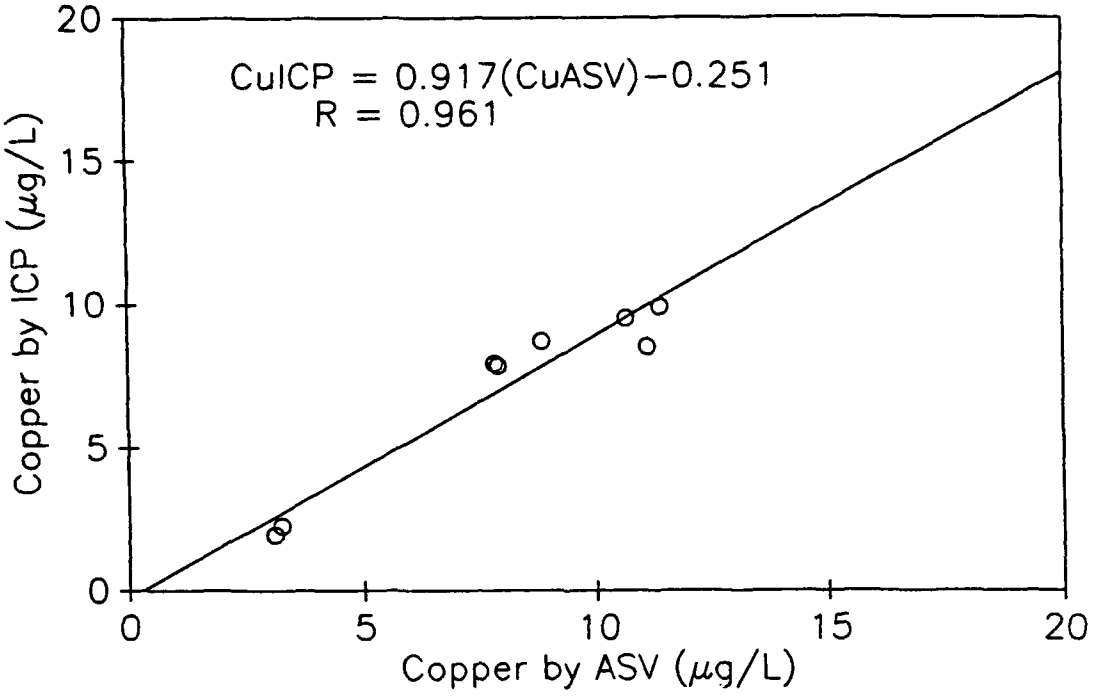


Figure 11. Regression between copper ASV and ICP for samples collected and analyzed on September 17, 1987.

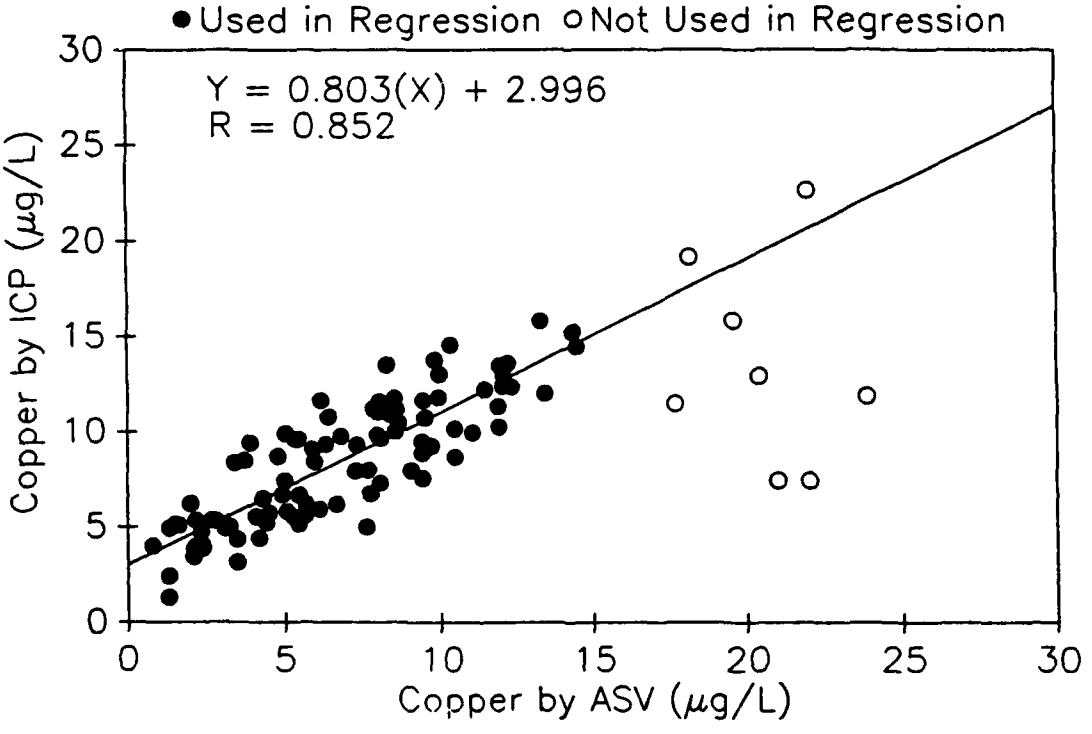


Figure 12. Regression between copper ASV and ICP for all data collected during the study.

correlation coefficient ($p<0.01$) of 0.75 was obtained from the correlation between all of the ASV and ICP data. However, for the data with ASV values above 2.5×10^{-7} Cu (15 µg/l), there was a locus of points away from the regression line. This suggests that the ASV method had a tendency to overestimate the copper concentrations above 15 µg/l compared to the copper concentrations determined by ICP analysis.

Organotin concentrations. The highest concentrations of TBT were consistently measured at the Silvergate station (figure 8B). Relatively high concentrations of TBT were also measured at the Southwestern station, moderate TBT levels were measured at the Harbor Police station, and the NOSC station had the lowest concentrations of TBT (figure 8B and table 5). These measurements indicate that a distinct TBT gradient was present during the study. The highly variable nature of this gradient is evidenced by the range of the 95% confidence intervals graphed for each station.

The highest concentrations of the organotin degradation products, DBT and MBT, were also measured at the Silvergate station. High concentrations of DBT and MBT corresponded to high concentrations of TBT found there (figure 8B). The confidence intervals determined for DBT were less than those determined for TBT, indicating that DBT variability was dampened in relation to the parent compound TBT. However, the confidence intervals determined for MBT indicated that MBT formation is not solely dependent on the concentrations of TBT and DBT. The relatively constant proportion of TBT degradation products suggests a constant degradation of TBT in Shelter Island Yacht Basin (table 6).

Table 6. Percentage of butyltin species determined for each station in Shelter Island Yacht Basin. Percentages are from means of all samples taken from June 17, 1986, to January 23, 1987.

Station	Butyltin		
	TBT	DBT (percent)	MBT
NOSC	45	33	22
HPBD	48	39	14
SWYC	47	39	14
SILVER	46	42	12

The concentration of TBT, DBT, and MBT were consistently lowest at the NOSC station (figure 13). The variance among days determined for the TBT data was the highest at the NOSC station, which was about four times higher than the daily variance obtained for the other stations. The highest tidal variability in TBT concentrations occurred on day 52, while the lowest tidal variability was detected on day 93 (figure 13).

The concentrations of DBT and MBT were also more variable at the NOSC station, where the variance due to sampling days was about twice as high the daily variance observed for the other stations. The concentration of DBT was most variable on day 182 and the least variable on day 21 (appendix B). The concentration of MBT was most variable on day 42 and the least variable on day 10 (appendix B).

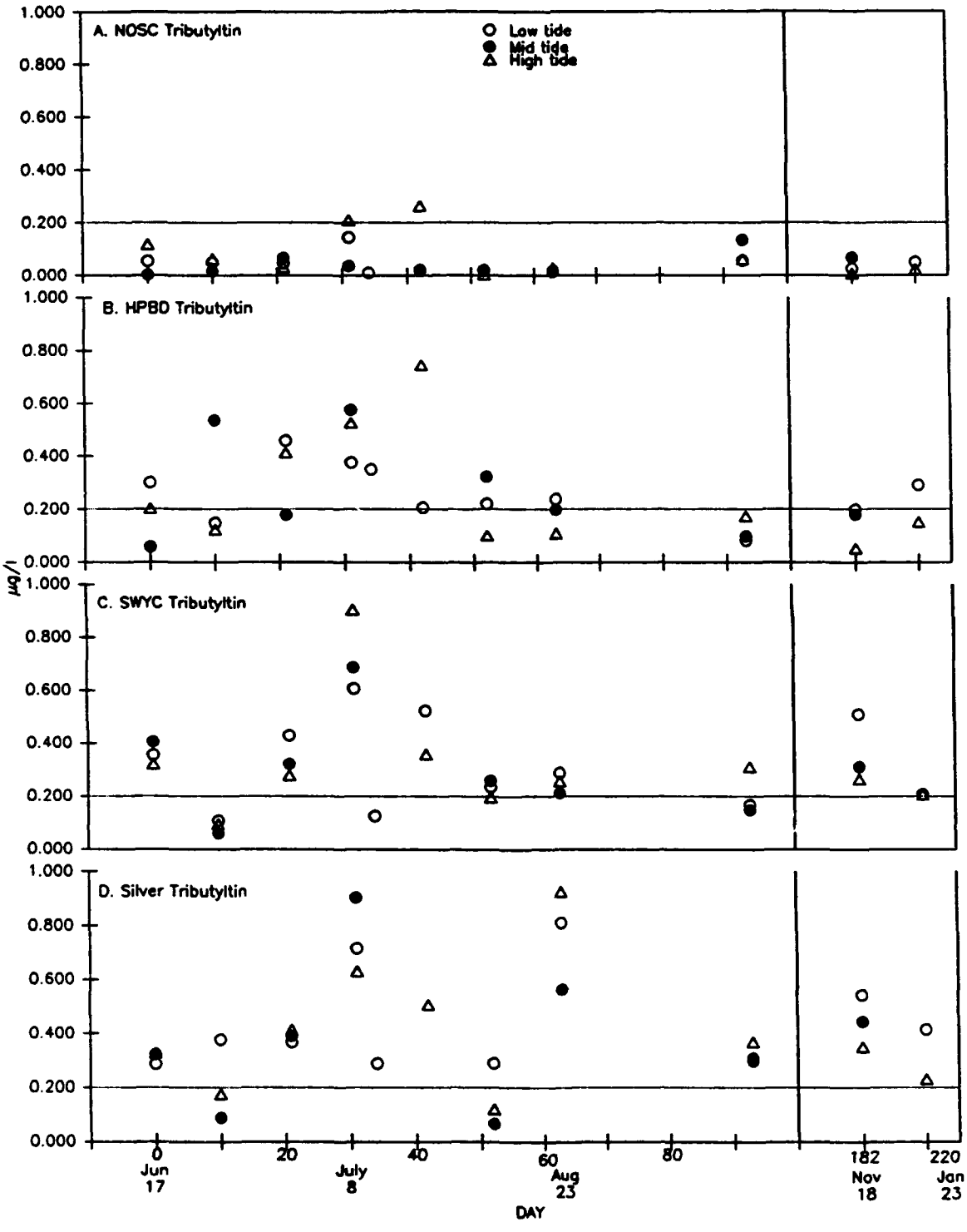


Figure 13. Tributyltin concentrations.

The toxic chemical results show that the NOSC station had significantly lower chemical concentrations but had higher variability among sampling days. In contrast, the Southwestern and Silvergate stations located within the yacht basin had significantly higher concentrations, but lower variability among sampling days, suggesting that the toxic chemical gradient was more constant within the yacht basin.

Environmental data. The mean temperature was slightly lower at the NOSC station, while the mean values of dissolved oxygen and pH were fairly constant between the stations (table 5, figures 8C and 8D). The slight differences between stations measured for the physical variables indicate that the physical variables, as measured during this part of the study, were only a minor contribution to the environmental gradient present in the yacht basin.

Semisynoptic Survey

Water quality data collected using the Marine Environmental Survey Craft (MESC) on August 8, 1986 (day 52), were used to evaluate water quality gradients in the Shelter Island Yacht Basin during incoming and outgoing tidal conditions. Data were collected along transects extending from the Naval Ocean Systems Center pier 159 through the yacht basin and returning on a reverse transect (figure 14). Time series plots from the horizontal survey provide snapshots of the dynamic variability of the environmental conditions within the yacht basin during a typical tidal cycle (figures 15 to 18). Statistically significant differences (one-way ANOVAs, $P<.05$) were detected between the areas of the yacht basin for temperature, salinity, dissolved oxygen, transmittance, pH, chlorophyll a fluorescence, and the responses from the cupric ion electrodes for both incoming and outgoing tide (figures 19 and 20).

Data collected using the MESC showed there were gradients of water quality variables between areas of the yacht basin. Temperature differed by about 0.5°C between the areas of the yacht basin during incoming tide (figures 15A and 19A) and by about 1.0°C during outgoing tide (figures 17A and 20A). Salinity within the yacht basin varied by about 0.1 °/oo with the highest salinity measured in the NOSC area during incoming tide (figures 15C and 17B) and near the Harbor Police boat dock during outgoing tide (figures 17C and 20B). Dissolved oxygen varied by less than 1.5 mg/l within the yacht basin (figures 19C and 20C) and increased slightly as temperature decreased at the entrance to the yacht basin (figures 15 and 17). Percent relative transmittance, a measure of water turbidity, varied by about 5% between the locations within the yacht basin during incoming tide (figures 15D and 19D) and increased to about 10% during outgoing tide (figures 17D and 19D). The average pH within the yacht basin varied by less than 0.05 pH units during incoming tide (figures 16C and 19E) and was slightly higher and more variable during outgoing tide (figures 18C and 20E). Chlorophyll a fluorescence, a measure of chlorophyll containing algae, was higher in the entrance of the yacht basin during incoming tide (figures 16D and 19F) and showed a decrease during outgoing tide (figures 18D and 20F).

In contrast, the cupric ion activity, as measured by the ion-specific electrodes, had a dramatic increased response upon entering the yacht basin and progressively increased farther into the Shelter Island Yacht Basin (figure 16). The electrodes provide a measure of the cupric ion activity and have been related to concentrations of dissolved copper in the water column (Zirino and Seligman, 1981; Lieberman et al., 1985; Johnston et al., 1986). However, it is not possible to directly relate the electrode response to copper concentration because the electrode's membrane becomes conditioned to the presence of copper and, therefore, the electrodes' response is not constant over time. Evidence of this is there were greater ranges of responses between the areas of the yacht basin during incoming tide than there were during outgoing tide for both electrodes (figures 16A-B, 18A-B, 19G-H, and 20G-H). This was because the outgoing tide measurements were made after the electrodes had been conditioned by the previous sampling.

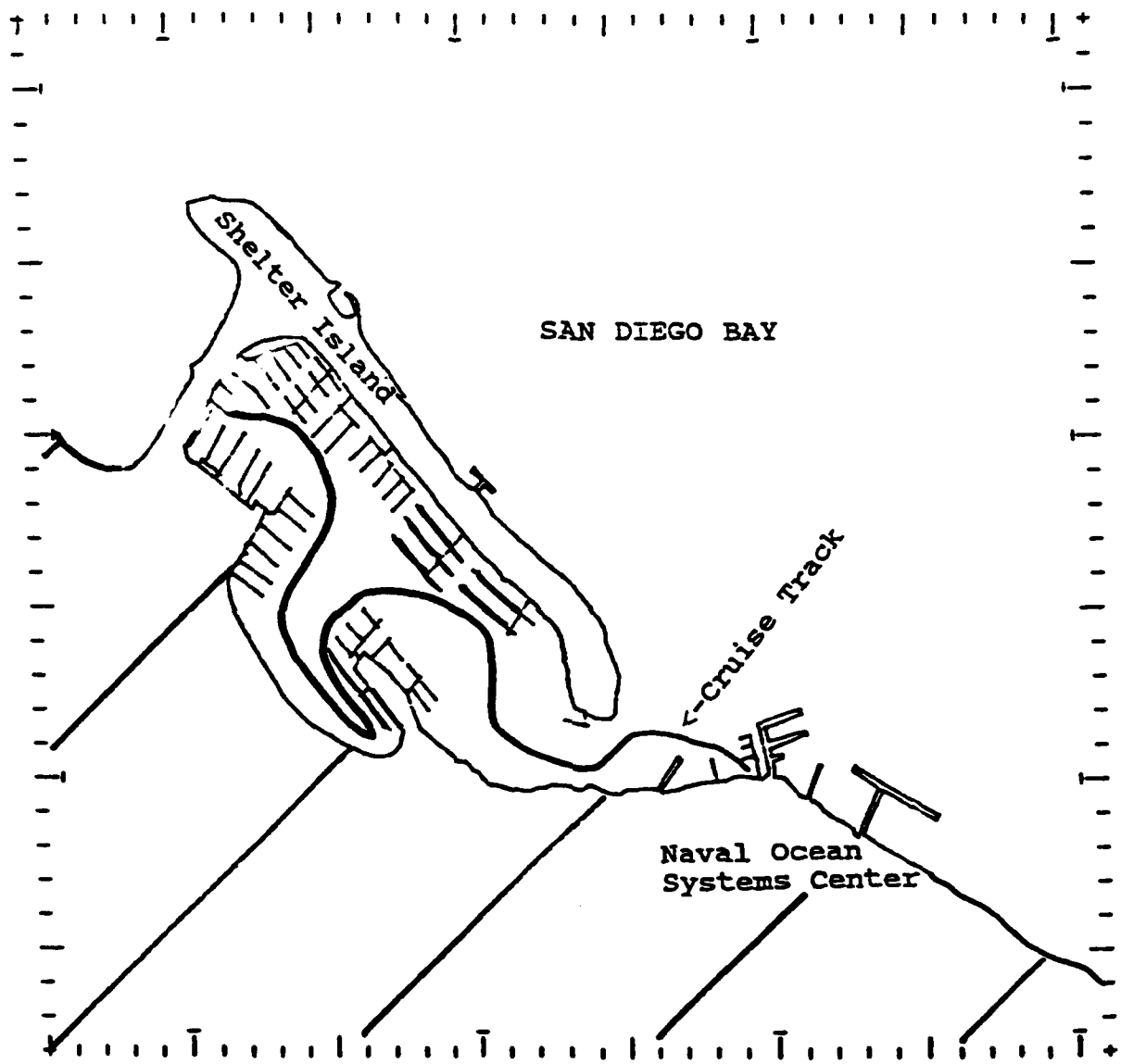


Figure 14. Transect followed by the Marine Environmental Survey Craft (MESC) during incoming and outgoing tide.

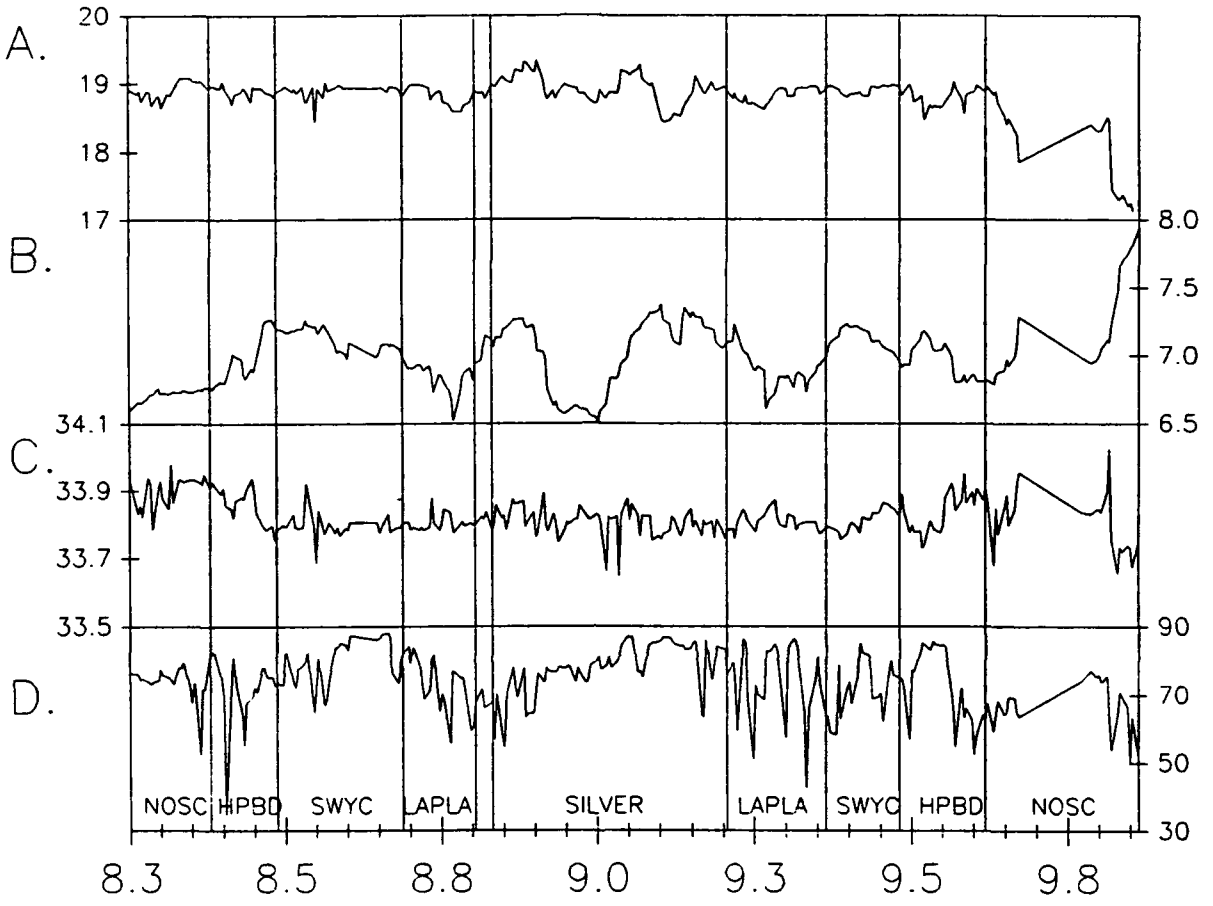


Figure 15. Time series of data collected by the MESC during incoming tide for (A) temperature (°C), (B) dissolved oxygen (mg/l), (C) salinity (°/oo), and (D) transmittance (%).

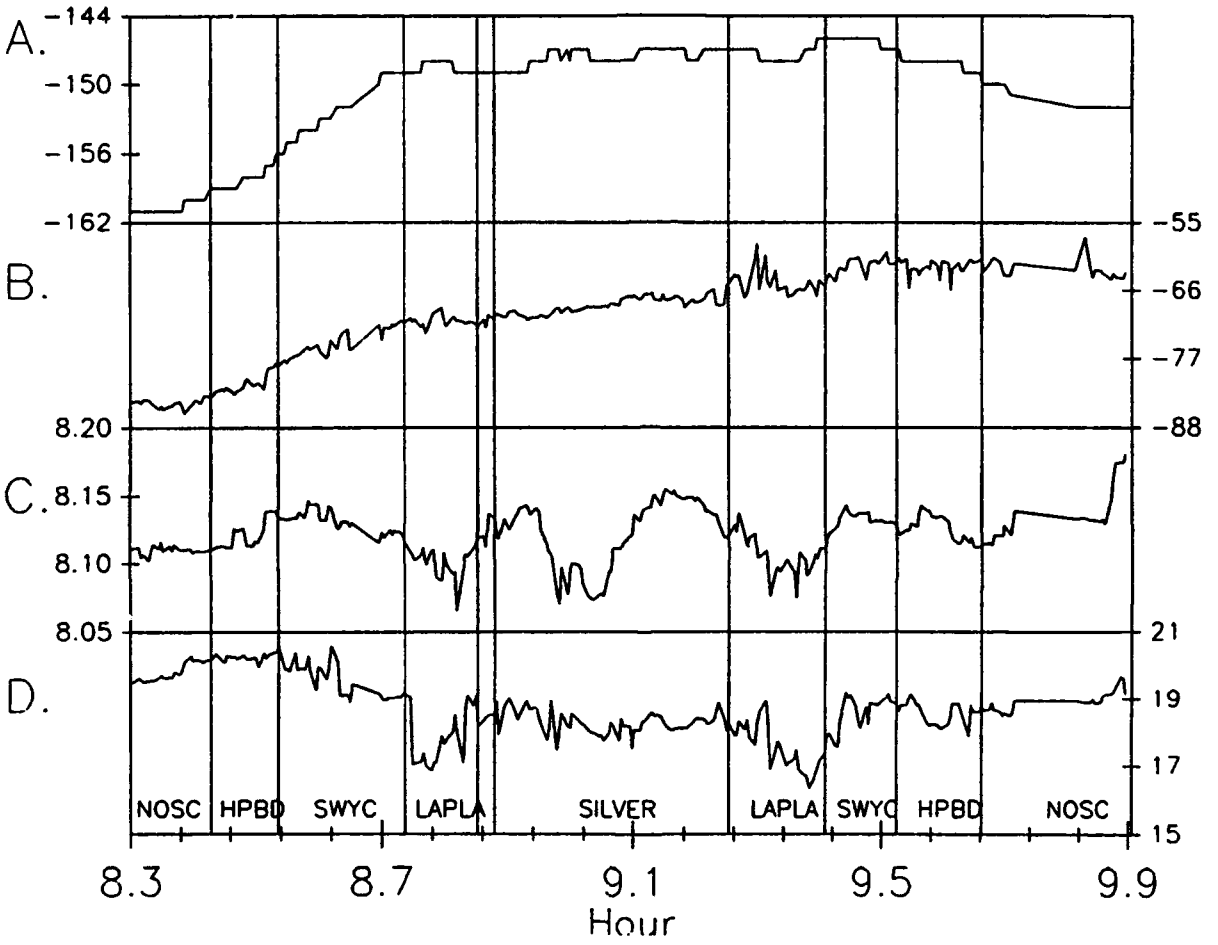


Figure 16. Time series of data collected by the MESC during incoming tide for Cu^{2+} activity (-mV) at electrode #1 (A) and #2 (B), pH (C), and chlorophyll fluorescence (D).

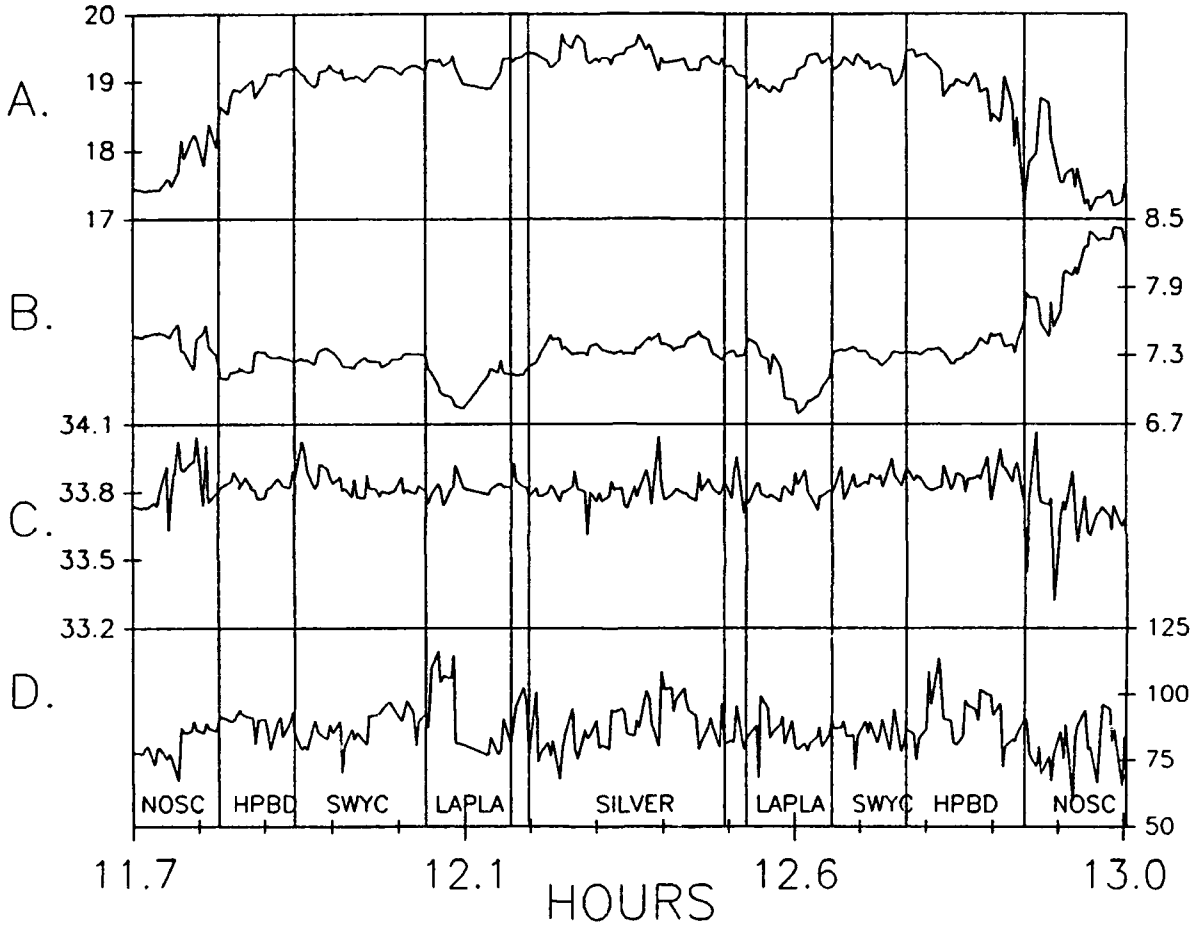


Figure 17. Time series of data collected by the MESC during outgoing tide for (A) temperature (°C), (B) dissolved oxygen (mg/l), (C) salinity (°/oo), and (D) transmittance (%).

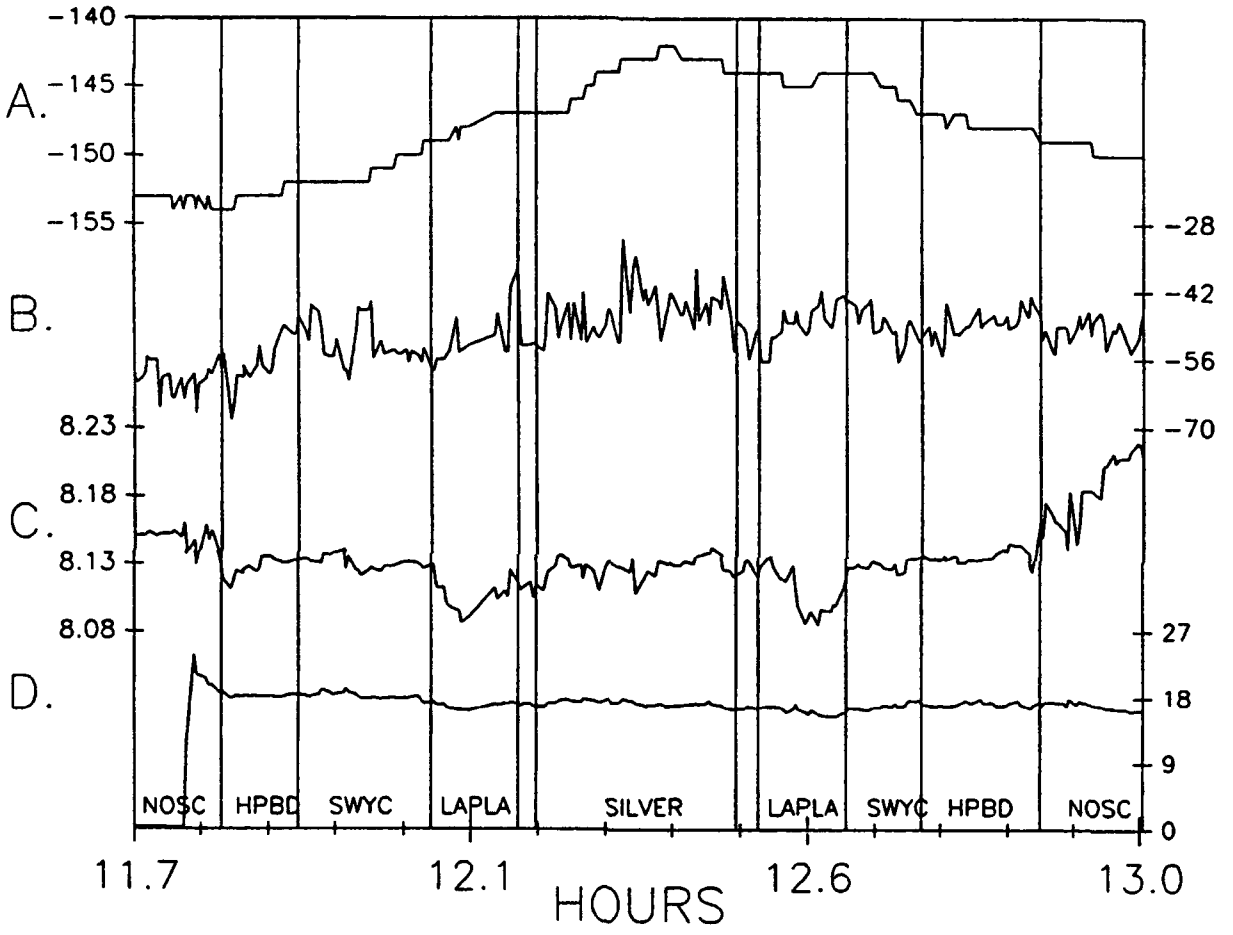


Figure 18. Time series of data collected by the MESC during outcoming tide for Cu^{2+} activity (-mV) at electrode #1 (A) and #2 (B), pH (C), and chlorophyll fluorescence (D).

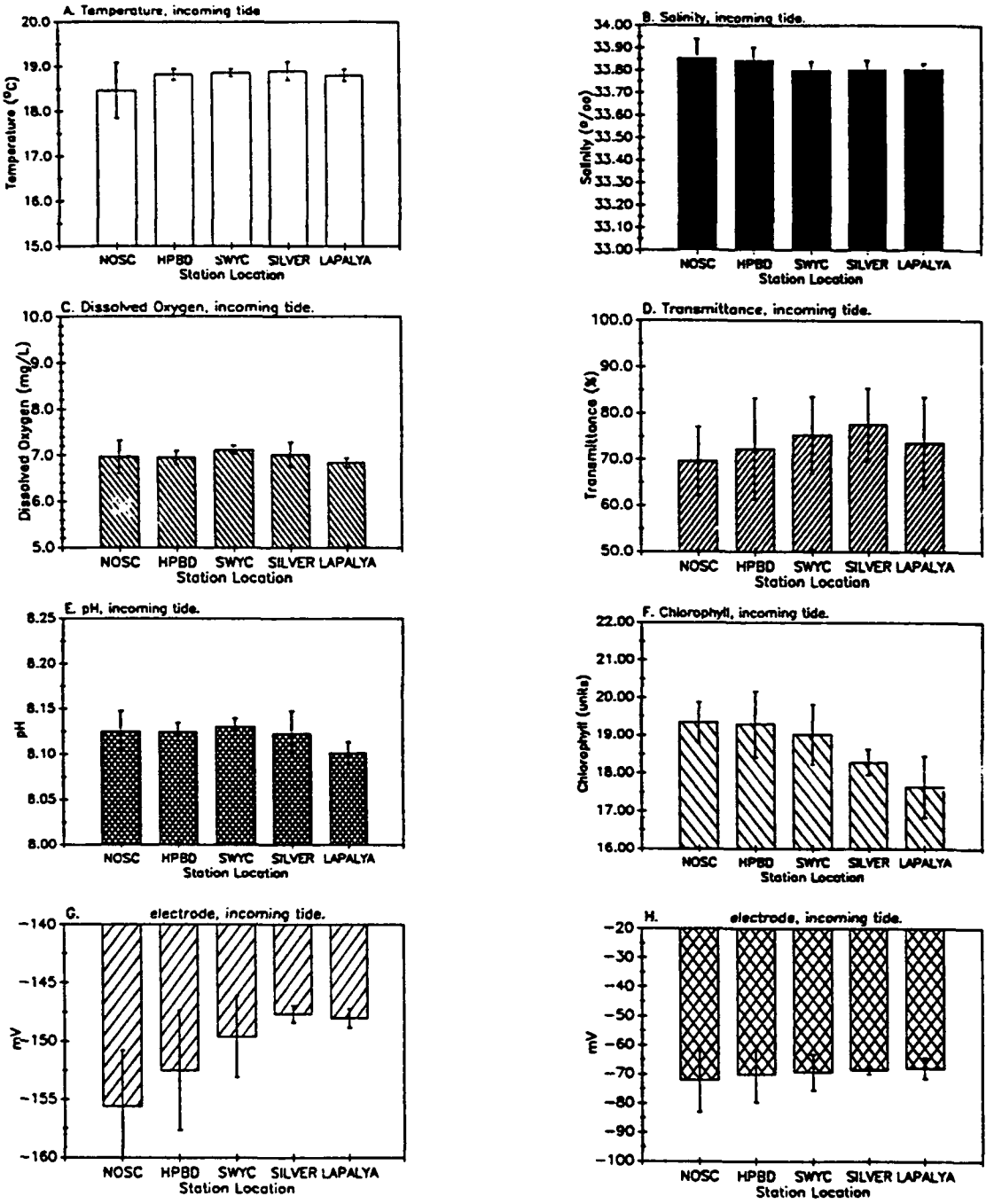


Figure 19. Water quality data during incoming tide.

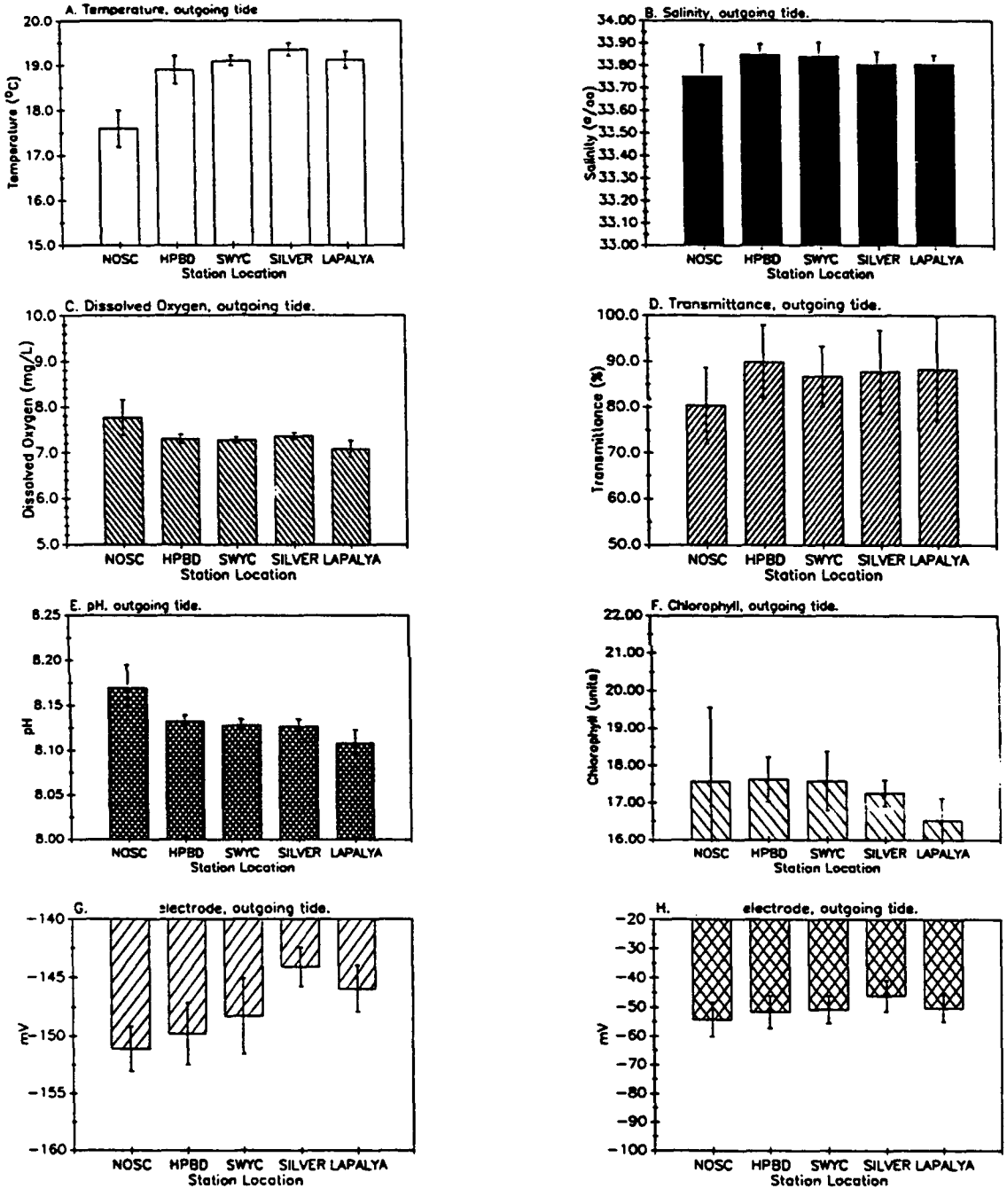


Figure 20. Water quality data during outgoing tide.

The correlation matrices obtained for the data from the incoming tide transect, outgoing tide transect, and the two transects combined are shown in table 7. The high number of significant correlations obtained from the analysis showed that the water quality variables were closely related in their distribution and variability in the yacht basin.

Table 7. Correlation matrices for data obtained from semisynoptic survey of Shelter Island Yacht Basin during incoming (A) and outgoing (B) tides. Included in the correlation are bottom depth (BOTTOM), turbidity (TURB), chlorophyll (CHLOR), and distance from main channel (DIS) (df > 225, significant r > .138, alpha = 0.05).

(A) Incoming Tide

	TEMP	SAL	DO	TURB	BOTTOM	pH	Cu[1]	Cu[2]	CHLOR	DIS
TEMP	1.0000									
SAL	0.2543	1.0000								
DO	-0.4134	-0.3812	1.0000							
TURB	0.1790	-0.0892	-0.0214	1.0000						
BOTTOM	-0.2269	0.0643	0.2606	-0.2431	1.0000					
pH	-0.3666	-0.2252	0.9037	-0.0129	0.3376	1.0000				
Cu[1]	0.0335	-0.4402	0.1802	0.0908	-0.0926	0.0203	1.0000			
Cu[2]	-0.2664	-0.3289	0.2690	-0.0794	0.1142	0.1827	0.8441	1.0000		
CHLOR	-0.0701	0.2671	0.1508	-0.0859	0.2452	0.3132	-0.7641	-0.6031	1.0000	
DIS	0.4227	-0.3358	-0.1443	0.2563	-0.3771	-0.3253	0.6290	0.1785	-0.5653	1.0000

(B) Outgoing Tide

	TEMP	SAL	DO	TURB	BOTTOM	pH	Cu[1]	Cu[2]	CHLOR	DIS
TEMP	1.0000									
SAL	0.3412	1.0000								
DO	-0.7674	-0.3926	1.0000							
TURB	0.2291	0.0629	-0.2430	1.0000						
BOTTOM	-0.4177	-0.0745	0.4474	-0.0450	1.0000					
pH	-0.7777	-0.3648	0.9435	-0.2401	0.4569	1.0000				
Cu[1]	0.4348	-0.0384	-0.1276	0.0421	-0.2731	-0.2764	1.0000			
Cu[2]	0.1830	-0.0667	0.0626	-0.0990	-0.1863	-0.0382	0.5947	1.0000		
CHLOR	-0.0372	0.2091	-0.0578	0.0202	0.0417	0.0814	-0.5348	-0.3567	1.0000	
DIS	0.8063	0.1467	-0.6359	0.1723	-0.4488	-0.7377	0.6350	0.2792	-0.1834	1.0000

BIOLOGICAL DATA

Taxonomic Groups

The data obtained from the panels exposed in Shelter Island Yacht Basin for 9-week and 3-week periods from June 17 to August 23, 1986, were combined to form taxonomic groups for analysis (table 8). The variables analyzed were species richness (species/50 cm^2), biomass density (g/500 cm^2) and major taxa consisting of polychaete worm biomass (g/50 cm^2), bryozoan biomass (g/50 cm^2), ascidian biomass (g/50 cm^2), and the biomass (g/50 cm^2) of all other species (other-spp.), which consisted of algal and crustacean species. These groups were employed to allow generalized comparisons of community structure between the four sampling stations (figure 21). A list of species and the stations from which they were collected is given in table 9. An annotated list of species and a table summarizing the dry-weights determined for all species and taxa sampled during the study are included in appendix A. Photographs obtained from panels exposed in Shelter Island Yacht Basin are included in appendix C.

Table 8. Means and results of analysis of variance for biological variables collected on panels exposed for 9 weeks (A) and 3 weeks (B).

(A) 9-week panels

			STATION				
VAR	Units	n[a]	NOSC	HPBD	SWYC	SILVER	p[c]
SPP	spp/50 cm²	6	11.83	9.33	6.67	6.17	***
BIO	g/500 cm²	6	40.55	44.26	74.56	36.09	**
BRY	g/50 cm²	6	0.97	0.12	0.003	0.00012	***
POLY	g/50 cm²	6	0.94	1.13	5.76	2.48	***
ASC	g/50 cm²	6	0.32	0.32	1.23	0.46	**
OTH	g/50 cm²	6	0.08	0.03	0.11	0.007	*

(B) Weekly averages from 3-week panels

			STATION				
VAR	Units	n[b]	NOSC	HPBD	SWYC	SILVER	p[c]
SPP	spp/50 cm²	3	5.67	3.98	4.67	3.89	+
BIO	g/500 cm²	3	0.39	1.47	2.32	2.86	**
BRY	g/50 cm²	3	0.007	0.139	0.178	0.204	***
POLY	g/50 cm²	3	0.007	0.002	0.0002	0.0003	**
ASC	g/50 cm²	3	0.005	0.013	0.011	0.012	NS

[a] number of panels per station
[b] number of 3-week periods with 3 panels
[c] significant levels denoted as:

*** = $p \leq 0.001$
** = $0.01 \geq p > 0.001$
* = $0.05 \geq p > 0.01$
+ = $0.15 \geq p > 0.05$
NS = not significant

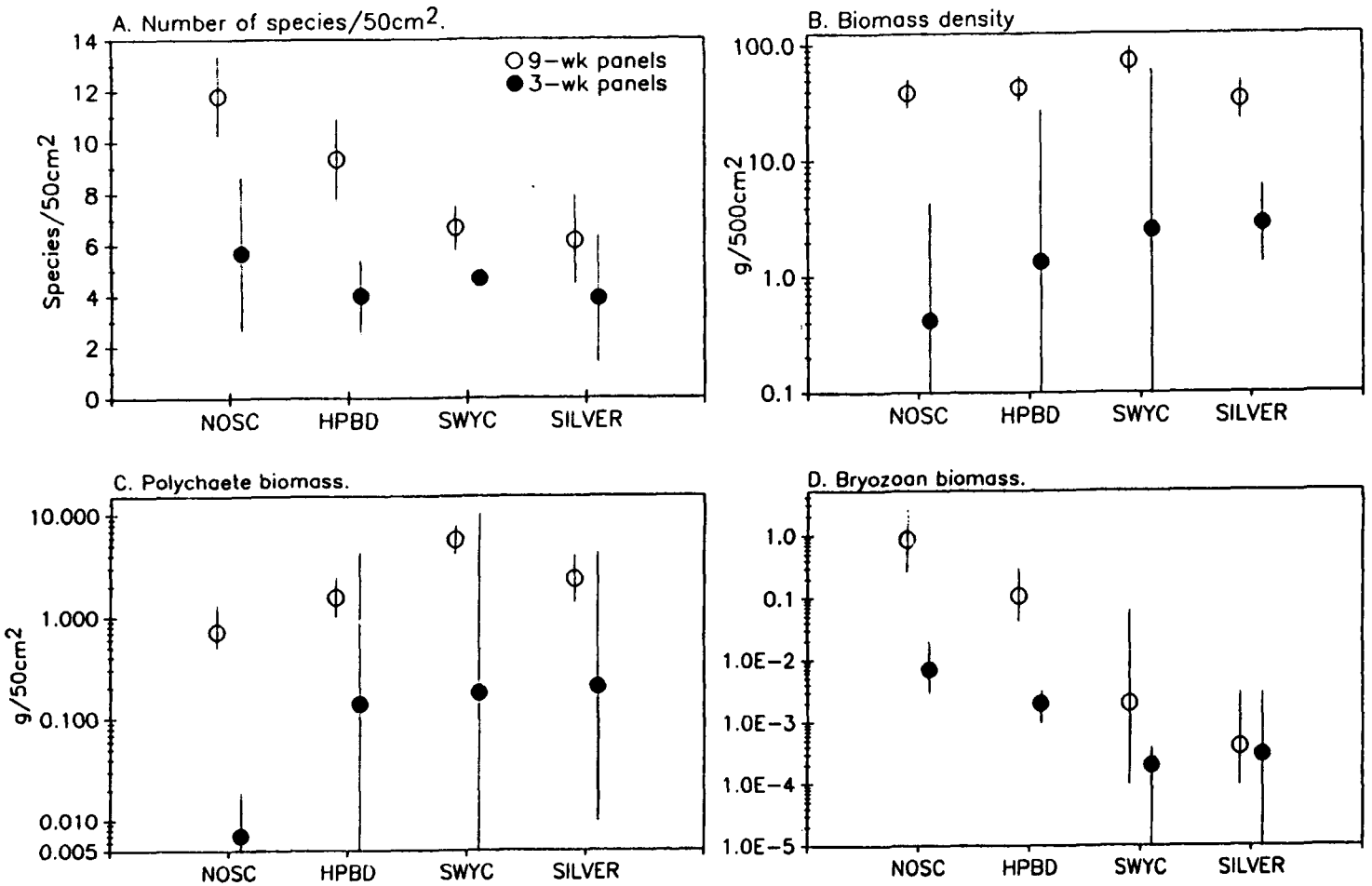


Figure 21. Means and 95% confidence intervals for biological data sampled from panels exposed for 9-week and 3-week periods.

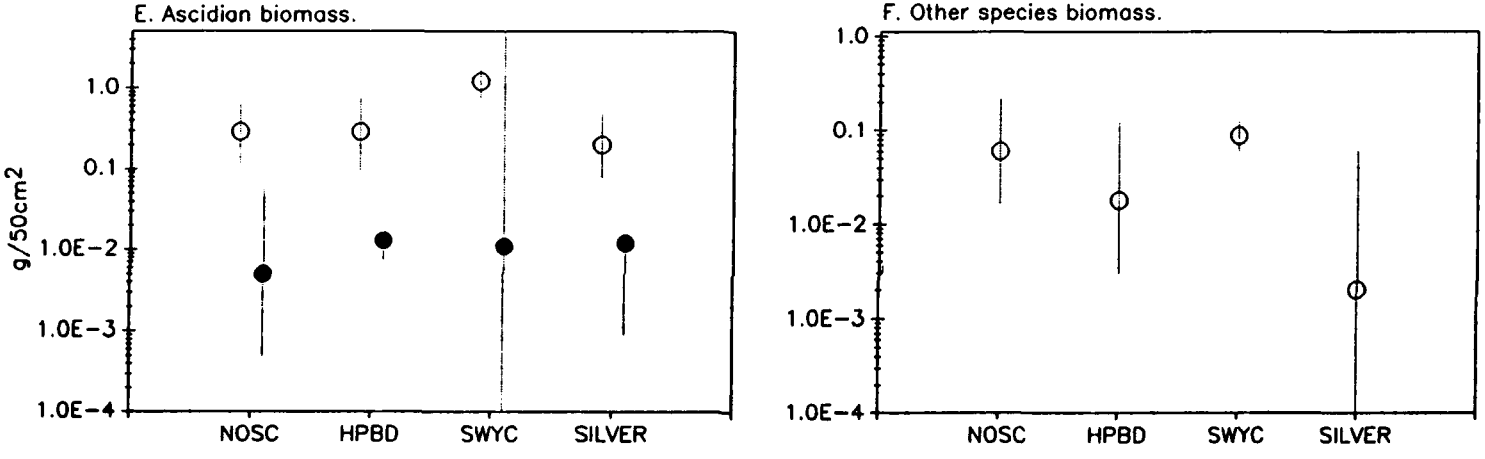


Fig 21. Continued.

Table 9. List of species. Species sampled on panels (P) and established communities (E) in Shelter Island Yacht Basin are listed for each station location.

Taxa or Species	Station Location			
	NOSC	HPBD	SWYC	SILVER
Kingdom Plantae (Algae)				
Phylum Rhodophyta				
Family Ceramiaceae	E			
Phylum Phaeophyta				
Scytosiphon lomentaria	P	E		
Kingdom Animalia				
Phylum Porifera				
Halichondria panicea	E	PE	E	
Haliclona sp.		E	E	E
Hymeniacidon sp.		E	E	
Leucosolenia sp.	E	PE	E	E
Phylum Cnidaria				
Class Hydrozoa	E			
Unidentified	P			
Phylum Annelida				
Class Polychaeta				
Family Serpulidae				
Hydroides pacificus	PE	PE	PE	PE
Spirorbis cf. *spirillum*	PE	PE	PE	PE
Order Errantia				
Family Nereidae (*Nereis* sp.)	P		E	P
Phylum Mollusca				
Class Gastropoda				
Family Acmaeidae (*Acmaea* spp.)	E	E		
Order Nudibranchia	P			
Class Pelecypoda(=Bivalvia)				
Mytilus edulis				
Phylum Arthropoda				
Order Thoracica				
Balanus spp.			E	
Balanus amphitrite	E			
Balanus glandula	E			
Balanus tintinnabulum	E			
Order Tanaidacea				P
Order Isopoda	P		PE	
Order Amphipoda	E			
Family Gammaridea				
Ericthonius sp.	PE	PE	PE	PE
Family Caprellidae				
Caprella sp.	P	P		
Order Decopoda				
Lophopanopeus sp.	E			
Pinnixa sp.	P	E		

Table 9. Continued.

Taxa or Species	Station Location			
	NOSC	HPBD	SWYC	SILVER
Phylum Ectoprocta (=Bryozoa)				
Order Cheilostomata				
Bugula sp.	E	PE	PE	P
Bugula californica	P		P	E
Bugula neritina	P	PE	E	P
Cryptosula pallasiana		E		
Hippodiplosia insculpta	PE			
Holoporella brunnea	PE	PE		
Membranipora sp.	P			
Schizoporella unicornis	P	PE	E	
Thalamoporella sp.	P			
Watersipora cf. *arcuata*	PE	PE	PE	PE
Order Ctenostomata				
Zoobotryon verticillatum	PE	E		
Phylum Chordata				
Subphylum Urochordata (=Tunicata)				
Class Ascidiacea				
Amaroucium californicum		PE		PE
Aplidium californicum	P	E	E	P
Botrylloides spp.	P			P
Botryllus spp.	P	PE	PE	PE
Ciona intestinalis	P	PE	PE	PE
Diplosoma spp.	P	PE	PE	PE
Polyclinum planum	P			
Pyura haustor	P		E	E
Styela spp.		P		P
Styela montereyensis	E		E	E
Styela plicata	E	PE	E	E
Styela truncata		P		

Panels exposed for 9 weeks. For the panels exposed for 9 weeks, the highest species richness was sampled at the NOSC station (figure 21A and table 8A), while the highest mean biomass density was sampled at the SWYC station (figure 21B and table 8A). The mean biomass of polychaete worms was also highest at the Southwestern station which was 2.3, 5.1, and 6.1 times higher than the mean polychaete biomass at the Silvergate, Harbor Police, and NOSC stations, respectively (figure 21C). The mean biomass of tunicate species was highest at the Southwestern station as well (figure 21E). The NOSC station had the highest mean biomass of bryozoan species, while both the NOSC and Southwestern stations had about the same mean biomass for other species (figures 21D and 21F and table 8A). The analysis of variance (ANOVA) of the biological data from the 9-week panels revealed statistically significant differences ($p<.05$) between stations for all groups (table 8A).

Species richness was negatively correlated with the mean concentrations of TBT, DBT, MBT, ASV, and ICP and with temperature (table 10A). Significant positive correlations were determined between species richness and bryozoan biomass and mean pH (table 10A). Biomass density had significant positive correlations with polychaete biomass and ascidian biomass. Polychaete biomass was negatively correlated with bryozoan biomass and positively correlated with the toxic chemical concentrations, while bryozoan biomass was negatively correlated with organotin and copper concentrations.

The negative correlations indicate that the bryozoan species abundance and the species richness had the tendency to decrease as pollution levels increased.

Table 10. Correlation matrix (Pearson Product Moment) between the biological and mean physical and chemical variables for the 9-week data set (A) and 3-week data set (B). (Variable names are defined in tables 2 and 3.)

(A) 9-week data set.

	SPP	BIO	POLY	BRY	ASC	OTH
BIO	-0.23					
POLY	-0.59**	0.48*				
BRY	0.82**	-0.13	-0.55**			
ASC	-0.09	0.55**	0.60**	-0.18		
OTH	0.36	0.28	0.13	0.18	0.34	
TBT	-0.82**	0.12	0.56**	-0.83**	0.06	-0.32
DBT	-0.84**	0.09	0.56**	-0.85**	0.04	-0.33
MBT	-0.78**	0.24	0.62**	-0.78**	0.18	-0.24
ASV	-0.84**	0.13	0.58**	-0.85**	0.07	-0.32
ICP	-0.85**	0.21	0.66**	-0.85**	0.17	-0.21
TEMP	-0.77**	-0.01	0.44*	-0.78**	-0.06	-0.40
pH	0.68**	-0.06	-0.40	0.66**	0.00	0.34
DO	-0.02	0.36	0.26	-0.01	0.31	0.15

(B) 3-week data set.

	SPP	BIO	POLY	BRY	ASC
BIO	-0.13				
POLY	-0.03	0.63**			
BRY	0.44*	-0.53**	-0.57**		
ASC	0.36	0.42*	0.62**	-0.28	
TBT	-0.43*	0.38	0.18	-0.59**	-0.22
DBT	-0.33	0.50*	0.28	-0.66**	-0.01
MBT	-0.40	0.32	0.24	-0.60**	-0.18
ASV	-0.40	0.38	0.21	-0.61**	-0.16
ICP	-0.17	0.56**	0.40	-0.68**	0.08
TEMP	-0.26	-0.64**	0.49*	-0.63**	0.16
pH	0.27	-0.36	-0.53**	0.03	-0.57**
DO	0.15	0.38	0.65**	-0.11	0.44*

*$0.05 > p < 0.01$
**$p < 0.01$

Multiple regression results were used to evaluate the ability of the independent variables to predict the dependent variables and explore possible cause and effect relationships between the independent variables and dependent variables. Results of multiple regression analysis of the biological (dependent variables) and mean toxic chemical concentrations (independent variables) revealed significant regression results for all the dependent variables (table 11). The toxic chemical data for copper determined by anodic stripping voltammetry (ASV), inductively coupled plasma spectroscopy (ICP), temperature, pH, and dissolved oxygen were omitted from the analysis because these data were too highly correlated with the other independent variables.

The regression results show that variability in the biological variables can be explained, in part, by variability in concentration of organotin compounds. These significant results are consistent with the idea that TBT, DBT, and MBT are important determinants in the community structure present at the four stations in Shelter Island Yacht Basin.

Table 11. Summary of the results of multiple regression of the taxonomic groups (dependent variables) and physical and chemical variables (independent variables) collected for the 9-week (A) and 3-week (B) periods of exposure. The proportion of variance explained by the regression (r^2), the independent variables with coefficients significantly different from 0 (coefficient), and the overall regression's p-value (p) are tabulated for each dependent variable.

(A) 9-week data set

Dependent Variable[a]	r^2	Coefficient					p[b]
SPP	0.7634	TBT*	DBT*	MBT*			***
BIO	0.5736	TBT***	DBT**	MBT***			***
POLY	0.7817	TBT***	DBT***	MBT***			***
BRY	0.7537	TBT+	DBT+	MBT+			***
ASC	0.5210	TBT***	DBT**	MBT***			***
OTH	0.3300	TBT*	DBT+	MBT*			*
(B) 3-week data set							
SPP	0.43	DBT+	ICP+	TEMP+			NS
BIO	0.72	DBT*	ICP+	TEMP*	pH*		**
POLY	0.82	DBT*	MBT*	ASV+	TEMP+	pH*	***
BRY	0.50						+
ASC	0.74	TBT*	DBT*	TEMP+	pH+		***

[a] full variable names are in table 3
[b] significance levels are denoted as
*** = $p \leq 0.001$
** = $0.01 \geq 0.001$
* = $0.05 \geq 0.01$
+ = $0.15 \geq 0.05$
NS = not significant

The relationship between the physical-chemical and biological data was further evaluated using principal component analyses (PCA) to obtain eigenvectors for the independent variables. The eigenvectors are linear combinations of the independent variables, which are constructed such that the first eigenvector will explain the maximum amount of variance in the independent variables; therefore, the principal components will effectively reduce the independent variables into one predictor variable. Regressions between the first eigenvector and the dependent variables resulted in significant regressions for species richness, bryozoan biomass, and polychaete biomass (table 12). The eigenvectors obtained from the principal component analysis are linear combinations of the independent variables used in the analysis and can be considered as vectors describing the toxic chemical, physical, and environmental gradients.

The principal components obtained from the eigenvector derived from the toxic chemical variables were better at predicting the dependent variables than were the principal components obtained from

Table 12. Results from principal component analysis (PCA) and regression of first eigenvector on biological variables for 9-week data set. The independent variables used in the PCA, the eigenvector, the percent of variance in the independent variables explained by the eigenvectors (var.), the regression equation for significant regressions of the biological variables, the regression coefficient (r^2) and the significance level are tabulated for the toxic chemical variables (A), the physical variables (B), and for both the physical and chemical variables (C).

	Independent Variables	Eigen-vector	Var.	Equation	r^2	P[b]
(A)	Toxic Chemical Gradient[a] TBT DBT MBT ASV ICP	TOX1	94.6%	SPP = 1.04 (TOX1) + 8.5 BRY = 0.63 (TOX1) −2.1 POLY = −.36 (TOX1) + 1.1	0.72 0.73 0.37	*** *** ***
(B)	Physical Gradient TEMP pH DO	PHY1	70.3%	SPP = 1.27 (PHY1) + 8.5 BRY = −.73 (PHY1) − 2.1 POLY = 0.39 (PHY1) + 1.1	0.41 0.42 0.42	*** *** **
(C)	Environmental Gradient TBT DBT MBT ASV ICP TEMP pH DO	ENV1	81.4%	SPP = −.85 (ENV1) + 8.5 BRY = −.53 (ENV1) − 2.08 POLY = 0.29 (ENV1) + 1.1	0.67 0.68 0.32	*** *** ***

[a] variable names are listed in tables 2 and 3
[b] significance levels denoted as:
*** = $p \leq 0.001$
** = $0.01 \geq p > 0.001$
* = $0.05 \geq p > 0.01$
+ = $0.15 \geq p > 0.05$

the physical variables or the principal components obtained from both the toxic chemical and physical data (table 12). The utility of using the principal components as predictors is that they can be used to express multidimensional information in one dimension for other analyses such as linear regression (figure 22).

First and second order regressions between the toxic chemical vector and the 9-week biological data suggested a distinct linear relationship between species richness and bryozoan biomass (figure 22A and D). Nonlinear interactions were evident between biomass density and ascidian biomass, while the polychaete biomass was equally explained by both first and second order regressions (figure 22C). The placement of the mean concentrations of TBT, ASV, and ICP on the toxic chemcial vector (figure 22E) give an indication of their relative contribution to the toxic gradient.

Panels exposed for 3 weeks. Analysis of the data obtained from panels exposed in Shelter Island Yacht Basin for 3-week periods showed that there were significant differences between stations for biomass density, polychaete biomass, and bryozoan biomass and significant differences between sampling days for biomass density and polychaete biomass (table 8B and figure 21).

Correlation analysis showed there were significant negative correlations between bryozoan biomass and TBT, DBT, MBT, ASV, and ICP and that biomass density and polychaete biomass were significantly correlated (table 10B). Correlation coefficents between the toxic chemical data and the data for number of species, polychaete biomass, and bryozoan biomass were lower for the 3-week data than the 9-week data (table 10).

Results of multiple regression of the taxonomic groups (dependent variables) and mean toxic chemical concentrations (independent variables) revealed statistically significant regressions for biomass density, polychaete biomass, and ascidian biomass (table 11B), which means the variability in these dependent variables can be explained by at least some of the independent variables.

The results of principal component analysis (PCA) for the 3-week data set showed that the eigenvector TOX1 was better at predicting species abundance and bryozoan biomass than were the physical or environmental eigenvectors (table 13). The physical eigenvector PHY1 was better at predicting polychaete biomass as evidenced by the r^2 values obtained from the regression (table 13). The results of a linear regression on the toxic chemical principal components with the 3-week biological variables showed that the toxic chemical vector was able to predict the distributions of species richness and bryozoan biomass (figure 23). Species richness exhibited a linear response to the toxic chemical vector, while the polychaete and bryozoan biomass plots suggested nonlinear interactions with the toxic chemical vector (figures 23B-D).

Community Structure

To facilitate comparisons of community structure on the settling panels between and within stations, dominance-diversity curves were developed for both individual panels and for station means (based on six panels). The dominance-diversity curves were developed by plotting the relative abundance (percent of total biomass) versus taxon rank. Percentages were used to allow direct comparisons between varying amounts of biomass sampled on replicate panels. The log scale allowed data spanning four orders of magnitude to be effectively plotted. Symbols were employed to represent the species and taxocene groups used to construct the dominance-diversity curves. Generic symbols, such as squares, triangles, circles, and diamonds, were used to denote commonly occurring phyla, while unique symbols were used to represent individual species or lowest identifiable taxa. Unless otherwise noted, squares denote ascidian species, triangles denote bryozoan species, circles denote polychaete worms, and diamonds denote sponges. Rarely occurring species were represented using Greek symbols.

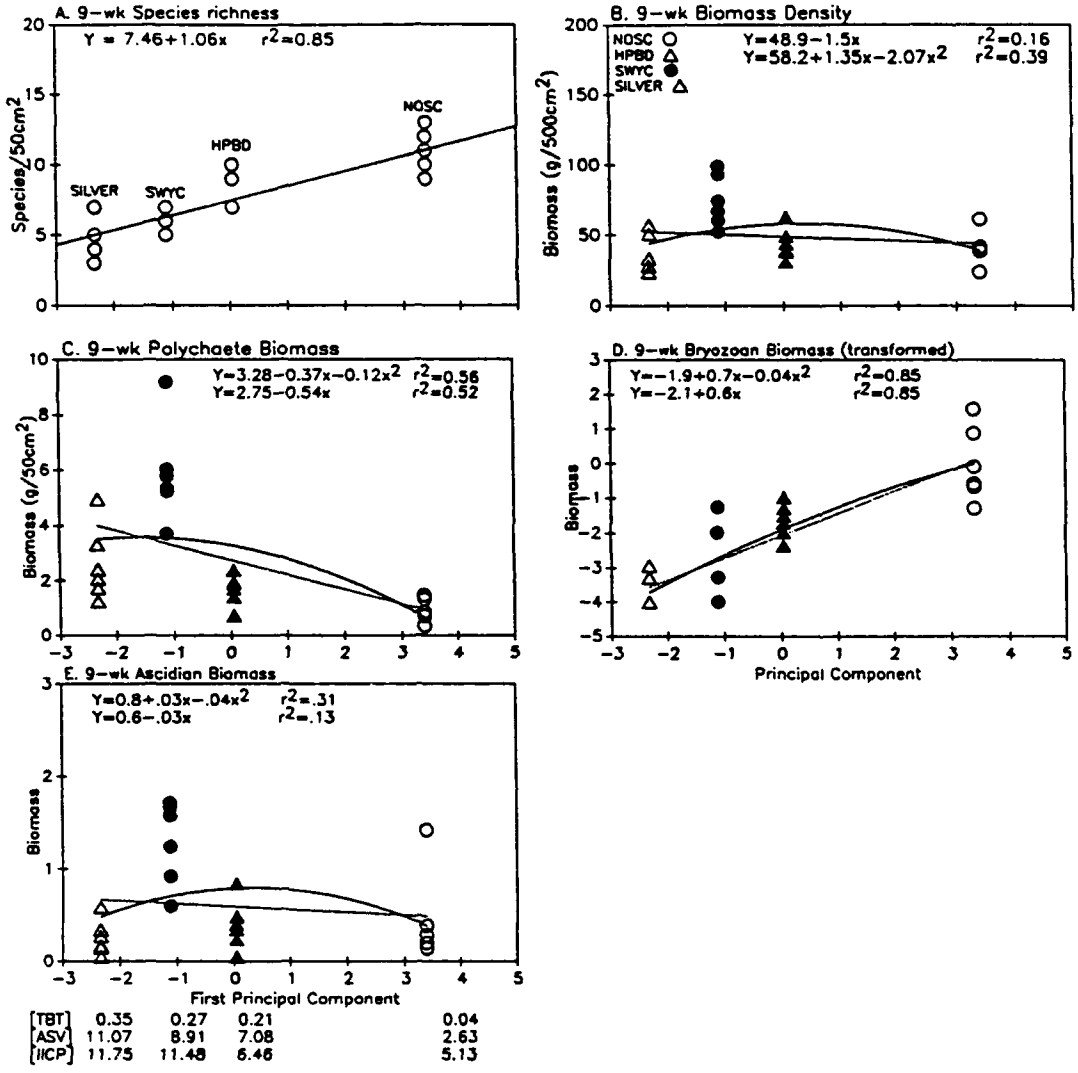


Figure 22. Bivariate plots of the toxic chemical principal components with biological variables obtained from panels exposed for 9 weeks. First-order and second-order regressions are plotted for each figure. The mean concentrations for TBT, ASV, and ICP are indicated for the toxic chemical vector (E).

Table 13. Results from principal component analysis (PCA) and regression of first eigenvector on biological variables for 3-week data set. The independent variables used in the PCA, the eigenvector, the percent of variance in the independent variables explained by the eigenvectors (var.), the regression equation for significant regressions of the biological variables, the regression coefficient (r^2), and the significance level are tabulated for the toxic chemical variables (A), the physical variables (B), and for both the physical and chemical variables (C).

	Independent Variables [a]	Eigen-vector	Var.	Equation	r^2	p[b]
(A)	Toxic Chemical Gradient TBT DBT MBT ASV ICP	TOX1	85.8%	SPP = 0.32 (TOX1) + 4.6 BIO = -.20 (TOX1) + 4.6 BRY = 0.16 (TOX1) - 3.5	0.23 0.07 0.42	*** + ***
(B)	Physical Gradient TEMP pH DO	PHY1	63.7%	SPP = -.35 (PHY1) + 4.6 BRY = -.26 (PHY1) - 0.26 POLY = -.20 (PHY1) - 1.5 ASC = -.05 (PHY1) - 1.9	0.11 0.17 0.42 0.36	+ * *** ***
(C)	Environmental Gradient TBT DBT MBT ASV ICP TEMP pH DO	ENV1	70.3%	SPP = 0.24 (ENV1) + 4.6 BIO = -.17 (ENV1) - 0.26 POLY = 0.12 (ENV1) - 3.4	0.15 0.19 0.35	* * ***

[a] variable names are listed in tables 2 and 3
[b] significance levels denoted as:
*** = $p \leq 0.001$
** = $0.01 \geq p > 0.001$
* = $0.05 \geq p > 0.01$
+ = $0.15 \geq p > 0.05$

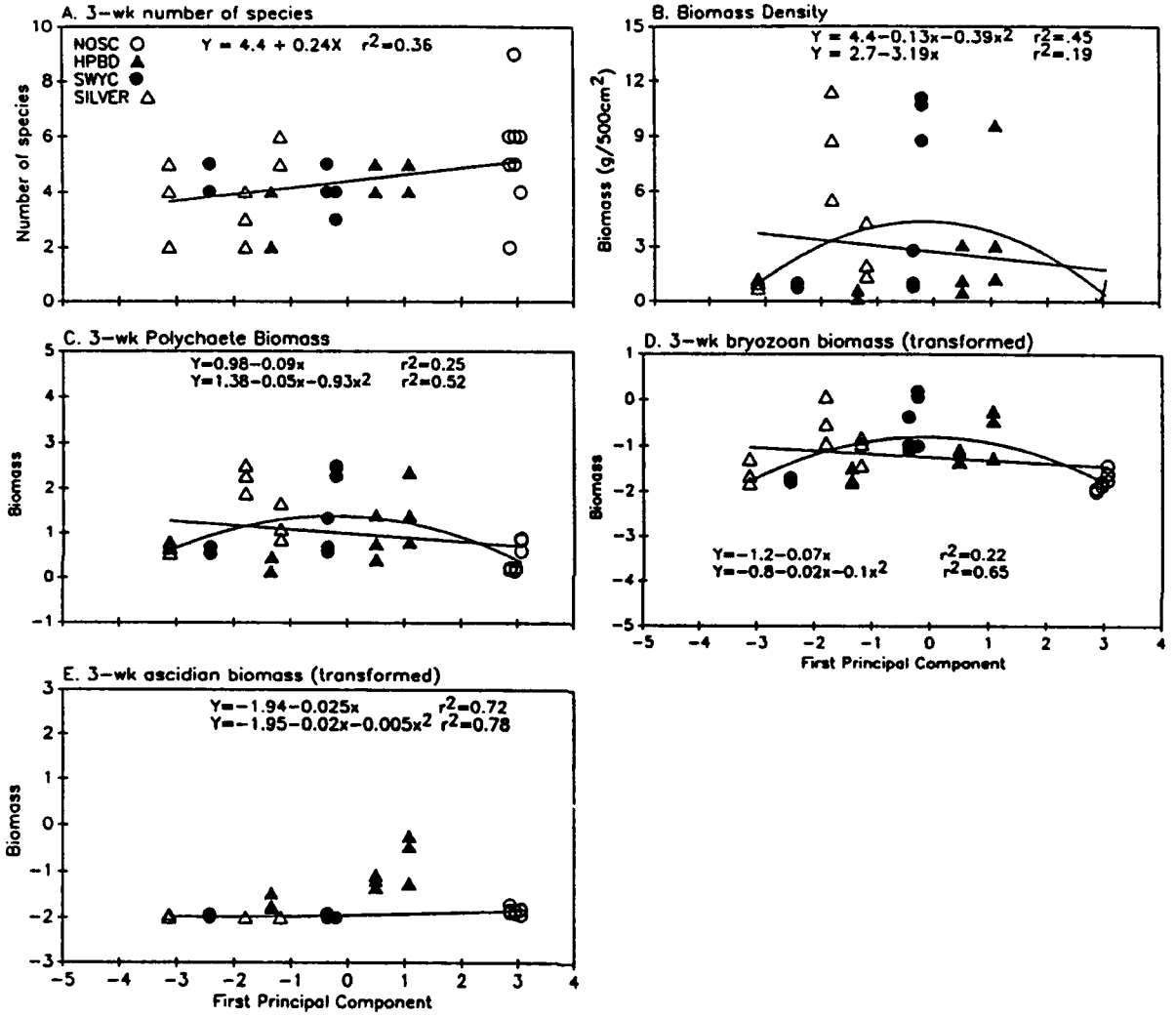


Figure 23. Bivariate plots of the toxic chemical principal components with biological data sampled from panels exposed for 3-week periods.

Panels exposed for 9 weeks. The most dominant species were the combination of the tube-building polychaete worms *Hydroides pacificus* and *Spirorbis* sp. (*Spirorbis* cf. *spirillum*), which accounted for 90.2%, 80.4%, and 73.9% of the mean biomass at the Silvergate, Southwestern, and Harbor Police stations respectively (figure 24). However, at the NOSC station, polychaete worms accounted for only 30.8% of the mean biomass, while the bryozoan species *Bugula neritina* was the most dominant form, accounting for 44.4% of the mean biomass.

At the Silvergate station two serpulid polychaetes (*H. pacificus* and *Spirorbis* sp.) were strongly dominant and only two other taxa (the tunicates *Diplosoma* spp. and *Botryllus* sp.) represented more than 1.0% of the biomass. There were six taxa with percentages of biomass sampled less than 1.0% that formed the tail of the mean dominance-diversity curve for the Silvergate station (figure 24). The tail of the curve was made of, in decreasing order of relative abundance, amphipods (primarily *Erichthonius brasiliensis*), *Ciona intestinalis*, *Botrylloides* sp., *Aplidium californicum*, errant polychaetes (primarily *Nereis* sp.), and finally *Bugula neritina*, whose biomass was about 0.04% of the relative mean biomass. The replicate panels for Silvergate station showed similar shape and species ordination, such that the respective dominance-diversity curves exhibited the form of straight lines or geometric series (figure 25).

The serpulid polychaete worms *H. pacificus* and *Spirorbis* sp. were also strongly dominant at the Southwestern and Harbor Police stations (figure 24). The dominance-diversity curves for replicate panels exposed for 9 weeks at the Southwestern station (figure 25) all show *H. pacificus* and *Spirorbis* sp. as the most dominant followed by *C. intestinalis*, *Diplosoma* spp., *Botryllus* sp., and amphipods which comprised relative biomass in the 10.0 to 1.0% range. The relative biomass of *Bugula neritina* increased to about 0.50%, compared to the extreme low biomass of *Bugula neritina* on the panels exposed at the Silvergate station (0.04%).

The polychaetes *H. pacificus* and *Spirorbis* sp. also dominated the panels exposed at the Harbor Police station (figure 26). The dominance-diversity curves constructed from the Harbor Police station were more curvilinear than those for the Silvergate or Southwestern stations. The curves for the Harbor Police station data had more evenly spaced ordination of species and longer tails, reflecting more species richness. Additional ascidian species were present (*Amoroucium californicum*, *Styela* spp., and an unidentified species), as were the sponges *Halichondria panicea* and *Leucosolenia* sp. The relative biomass of *Bugula neritina* (2.0%) also was higher than at the Silvergate and Southwestern stations.

The dominance-diversity curves obtained for replicate panels from the NOSC station were more curvilinear than those for the other stations (figure 27). Some of the curves exhibited an "S-shaped" curvature, which has been attributed to highly diverse communities (Whittaker, 1965). The "S-shaped" form resulted from clumps or groups of species forming loci in the relative abundance ranges of 50.0 to 20.0%, 9.0 to 5.0%, 2.0 to 0.8%, and 0.10 to 0.05% (figure 27).

The NOSC station had more curvature because more species were present. Most notable were the increased relative abundance and dominance of bryozoan species, which included (in decreasing order of abundance) *Bugula neritina*, *Holoporella brunnea*, *Watersipora* cf. *arcuata*, (Banta, 1969), *Membranipora* sp., *Zoobotryon verticillatum*, and *Schizoporella unicornis*. Other species also present at the NOSC station included an unidentified species of hydozoan, the decapod crab *Pinnixa franciscana*, large numbers of isopods (*Paracerceis* and *Idotea*), and nudibranchs. The replicate curves also illustrate the variability between panels (figure 27).

The dominance-diversity curves show there was a distinct species association present at each station. The community structure, as represented by the dominance-diversity curves, can be considered the response of the community to different environmental and ecological factors present at the four

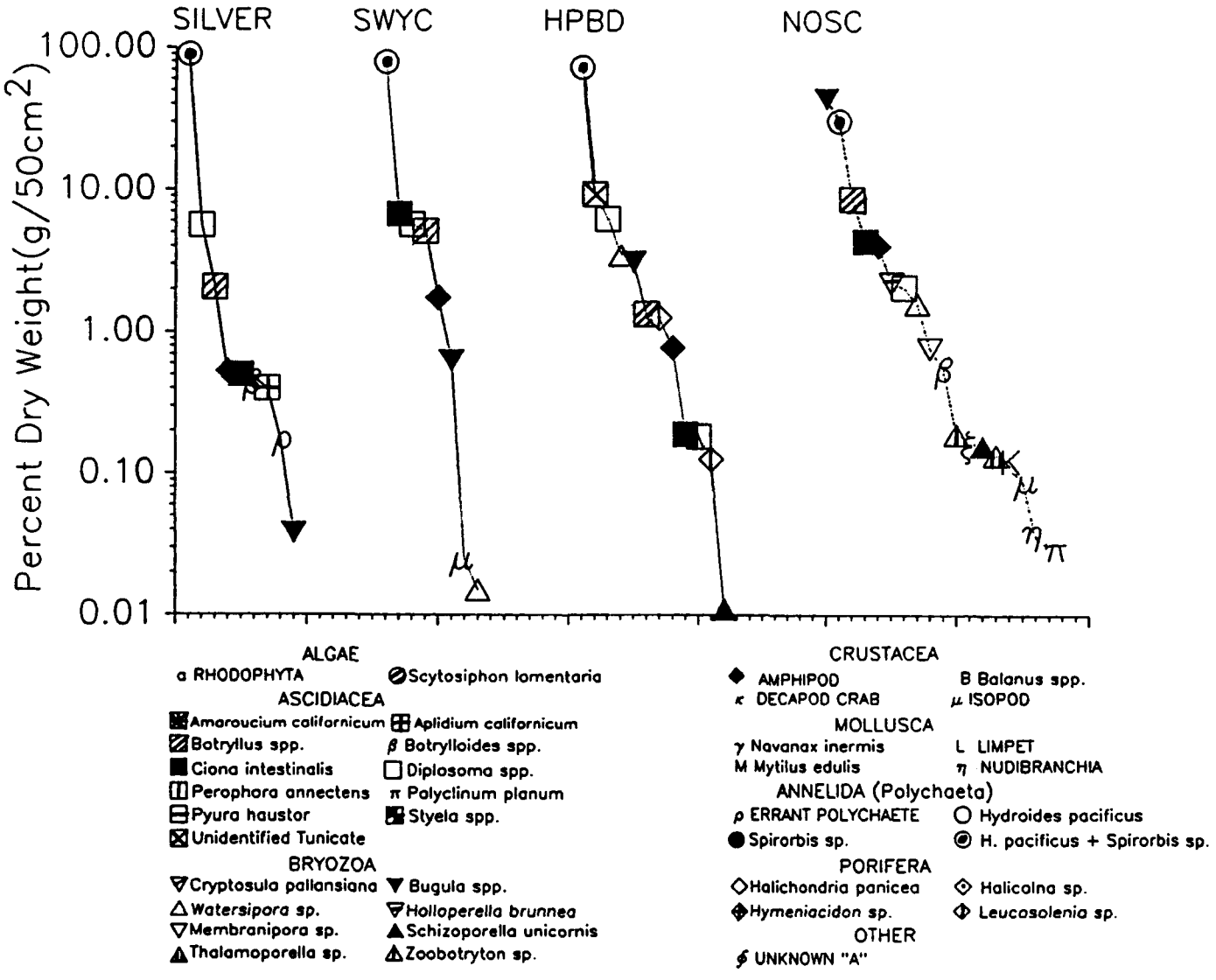


Figure 24. Mean dominance-diversity curves from 9-week panels.

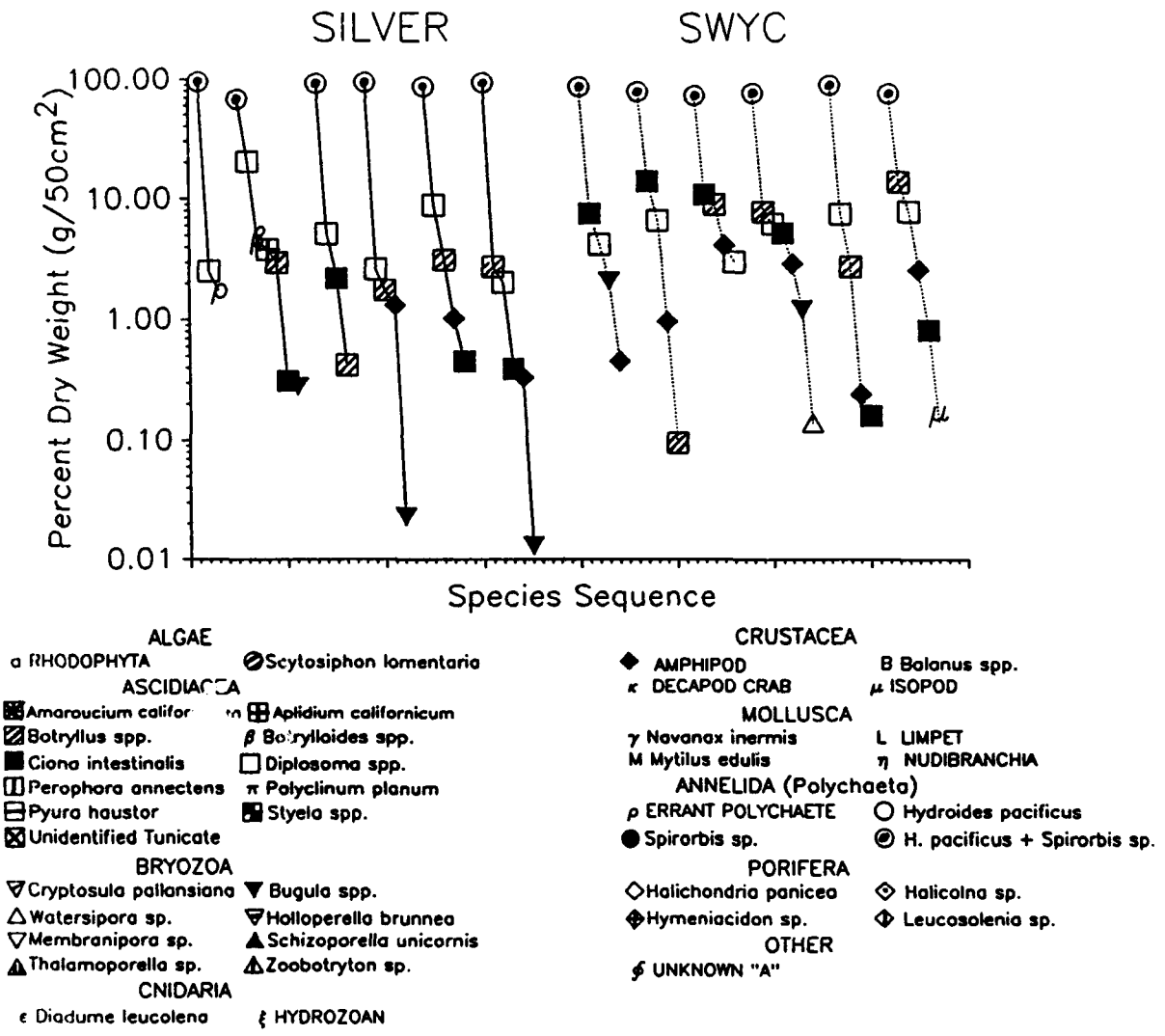


Figure 25. Dominance-diversity curves from replicate panels exposed for 9 weeks at the Silvergate Yacht Club (SILVER) and Southwestern Yacht Club (SWYC) stations.

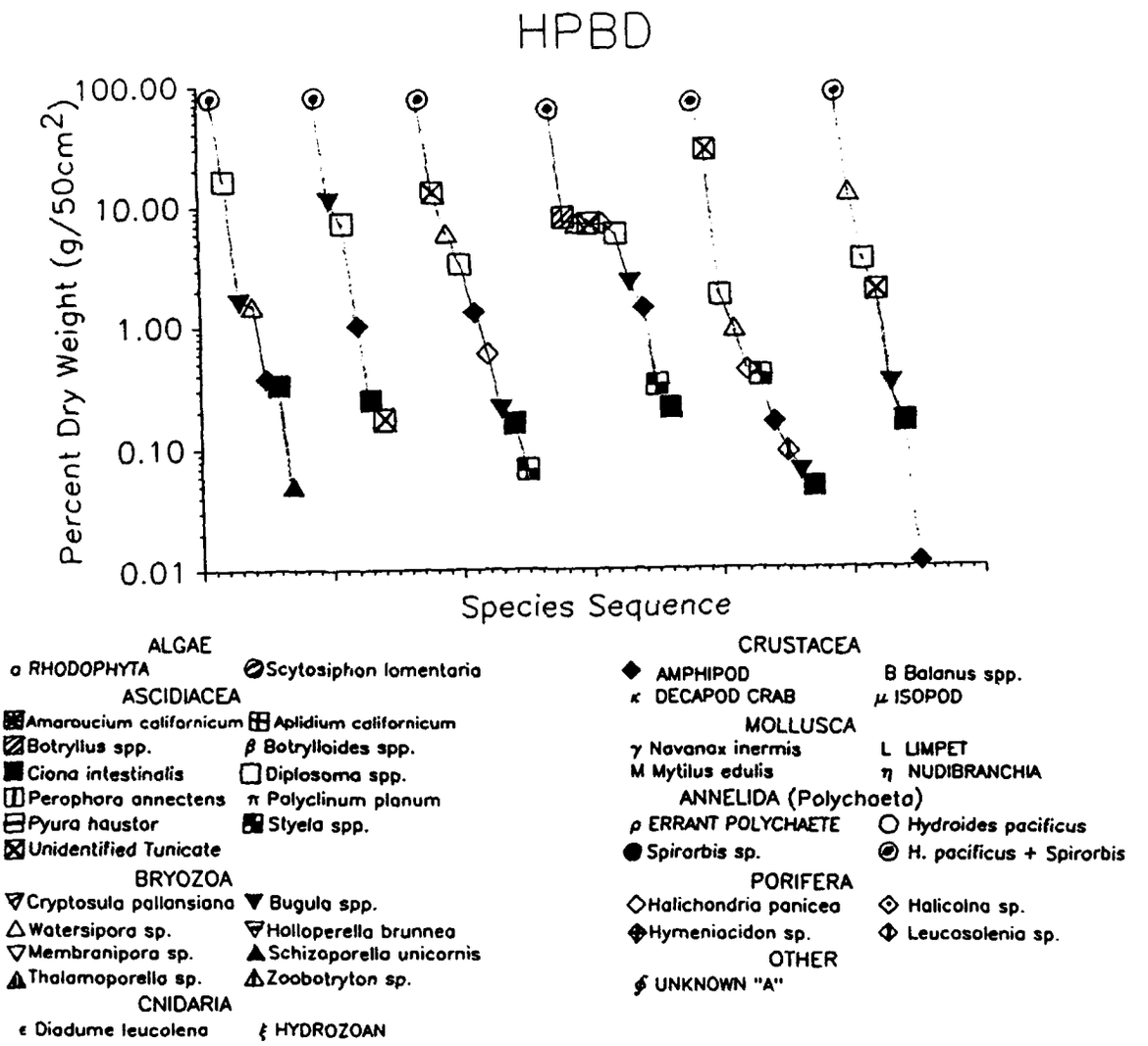


Figure 26. Dominance-diversity curves from replicate panels exposed for 9 weeks at the Harbor Police boat dock (HPBD) station.

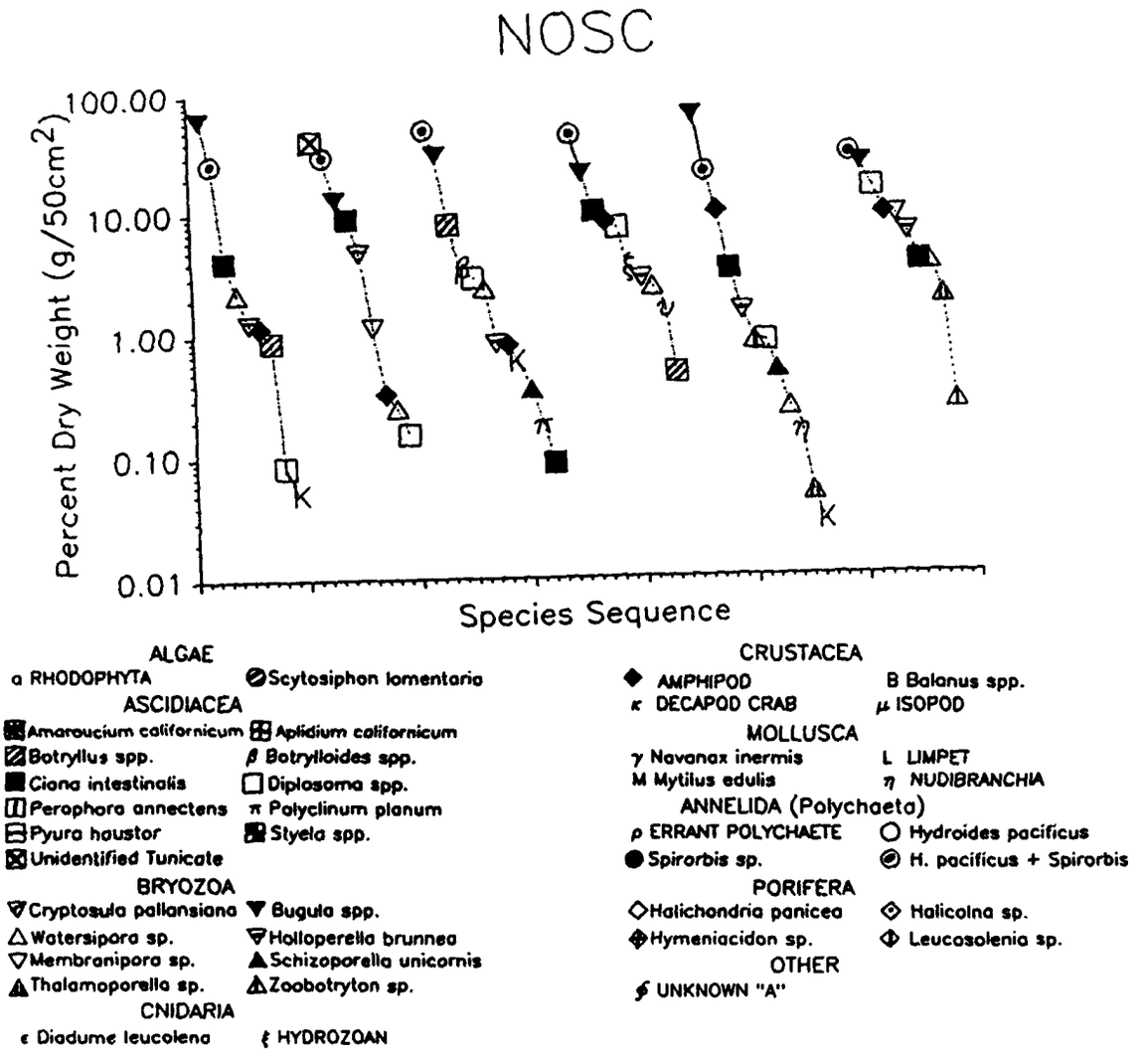


Figure 27. Dominance-diversity curves from replicate panels exposed for 9 weeks at the Naval Ocean Systems Center (NOSC) station.

stations. The concentrations of copper and organotin compounds were probably important factors in determining the resulting community structure, as the statistical results suggest.

Panels exposed for 3 weeks. The polychaete worm *H. pacificus* was dominant on all panels sampled during the first 3-week period, except for one panel at the NOSC station dominated by the algae *Scytosiphon lomentaria* (figure 28). The presence of algae confirms that one of the panels was exposed to sunlight during the 3-week period.

The replicate panels from the first 3-week exposure period (June 17 to July 8, figure 28), show the relative abundance of the polychaete worms, *H. pacificus* and *Spirorbis* sp. At the Silvergate station, the relative biomass of *H. pacificus* ranged from 66 to 82%, while the relative biomass of *Spirorbis* sp. ranged from 4.6 to 19.0%. For the panels from the Southwestern station, the biomass of *H. pacificus* was greater than 80% of the relative biomass, while the biomass of *Spirorbis* sp. ranged from 0.78 to 1.9% of the panel biomass. *H. pacificus* accounted for about 80% and *Spirorbis* sp. accounted for about 9% of the biomass at the Harbor Police station. However, on panels from the NOSC station, *H. pacificus* and *Spirorbis* sp. only accounted for 18% and 5% of the average biomass, respectively.

The tunicates *Diplosoma* sp., *Ciona intestinalis* and *Botryllus* sp. contributed 8.3%, 4.9%, and 1.0% of the mean biomass, respectively, for the Silvergate station (figure 28). At the Southwestern station, *Diplosoma* spp. and *Botryllus* sp. accounted for 6.8% and 0.4% of the mean biomass (figure 28). At the Harbor Police station, the only tunicates present were *Diplosoma* spp., which accounted for 5.6% of the mean biomass, and a few juvenile *Styela* sp., which were only sampled on one panel and comprised just 0.7% of the mean biomass (figure 28). At the NOSC station, *Diplosoma* spp. accounted for 9.1% of the biomass and the amount of bryozoan biomass was increased with *Bugula californica* and *Watersipora* cf. *arcuata* accounting for 3.9% and 2.6% of the mean biomass, respectively (figure 28). Also of note at the NOSC station was the presence of other unidentified species of gammarid amphipods (not *Ericthonius*), which were present with the algal species.

Similar patterns of settlement and colonization were also measured during the other two 3-week settlement periods, however there were some differences. During the second 3-week period (July 8 to July 29, figure 29) *Spirorbis* sp. biomass was higher than *H. pacificus* biomass on two of the panels exposed at the Silvergate station and on all of the panels exposed at the Harbor Police station. Settlement and colonization at the NOSC station was dominated by bryozoans (figure 29), most notable were *Holoporella brunnea* (33.8% of mean biomass), *Bugula neritina* (11.4%), and *Zoobotryon verticillatum* (8.14% of mean biomass). During the final 3-week period (July 29 to August 22, figure 30), the polychaete *H. pacificus* was clearly dominant on all the panels sampled. For the NOSC station, *H. pacificus* and a few individuals of *Spirorbis* sp. represented 67% of the mean biomass. For the other stations, *H. pacificus* comprised more than 79% of the mean biomass at the Southwestern station and more than 90% of the mean biomass at the Silvergate and Southwestern stations (figure 30).

The replicate panels from the 3-week exposure periods provide snapshots of the settlement and colonization process occurring at the respective stations. In comparison to the panels from the 9-week period, the 3-week panels provide a measure of variability in settlement that is dampened or masked in the data obtained from panels exposed for 9 weeks. This dampening is caused by differences in the time scales of exposure, and the result is an integration of environmental and ecological processes occurring during the interval.

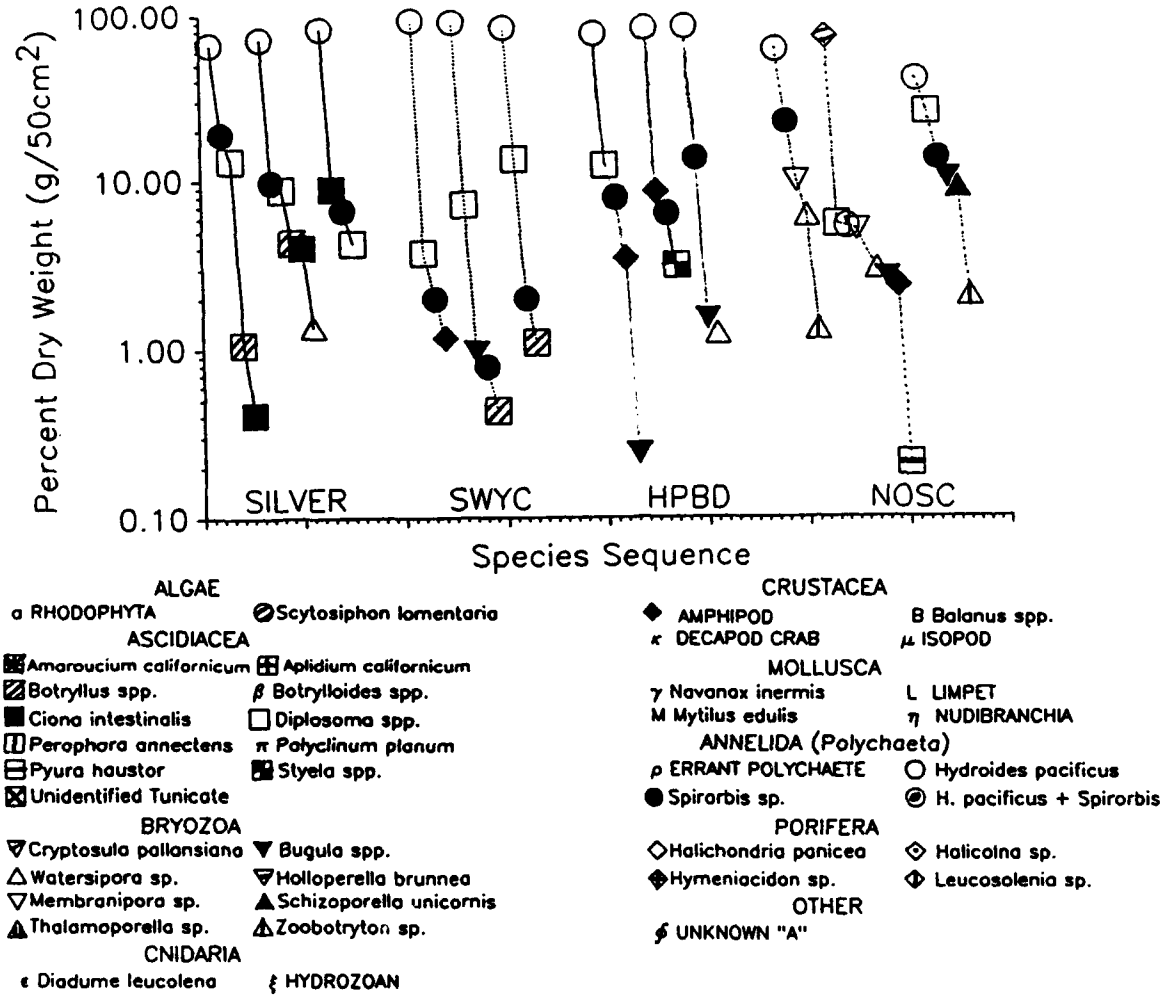


Figure 28. Dominance-diversity curves from replicate panels exposed for 3 weeks from June 17 to July 8, 1986 (Days 0 to 21).

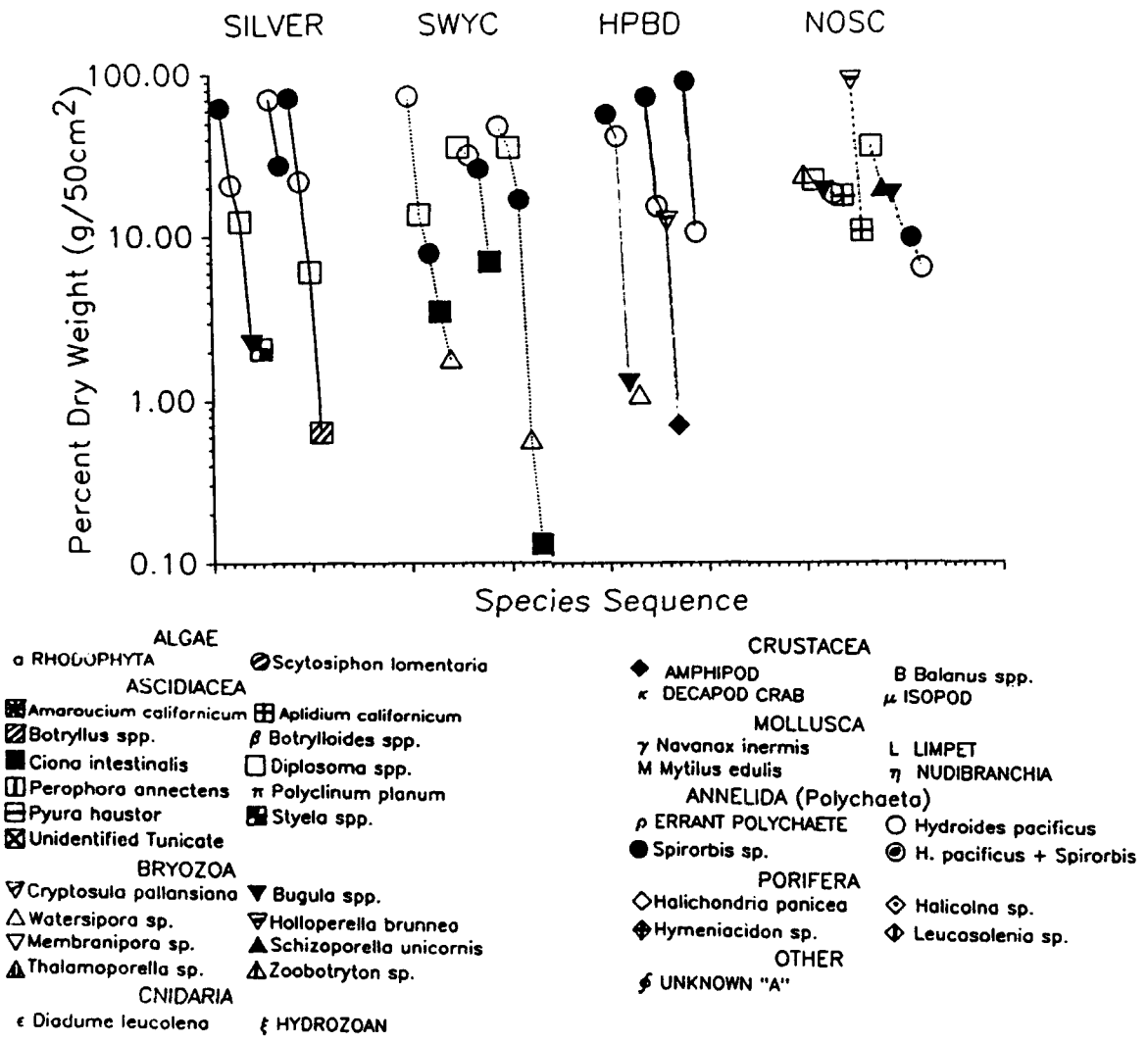


Figure 29. Dominance-diversity curves from replicate panels exposed for 3 weeks from July 8 to July 29, 1986 (Days 21 to 42).

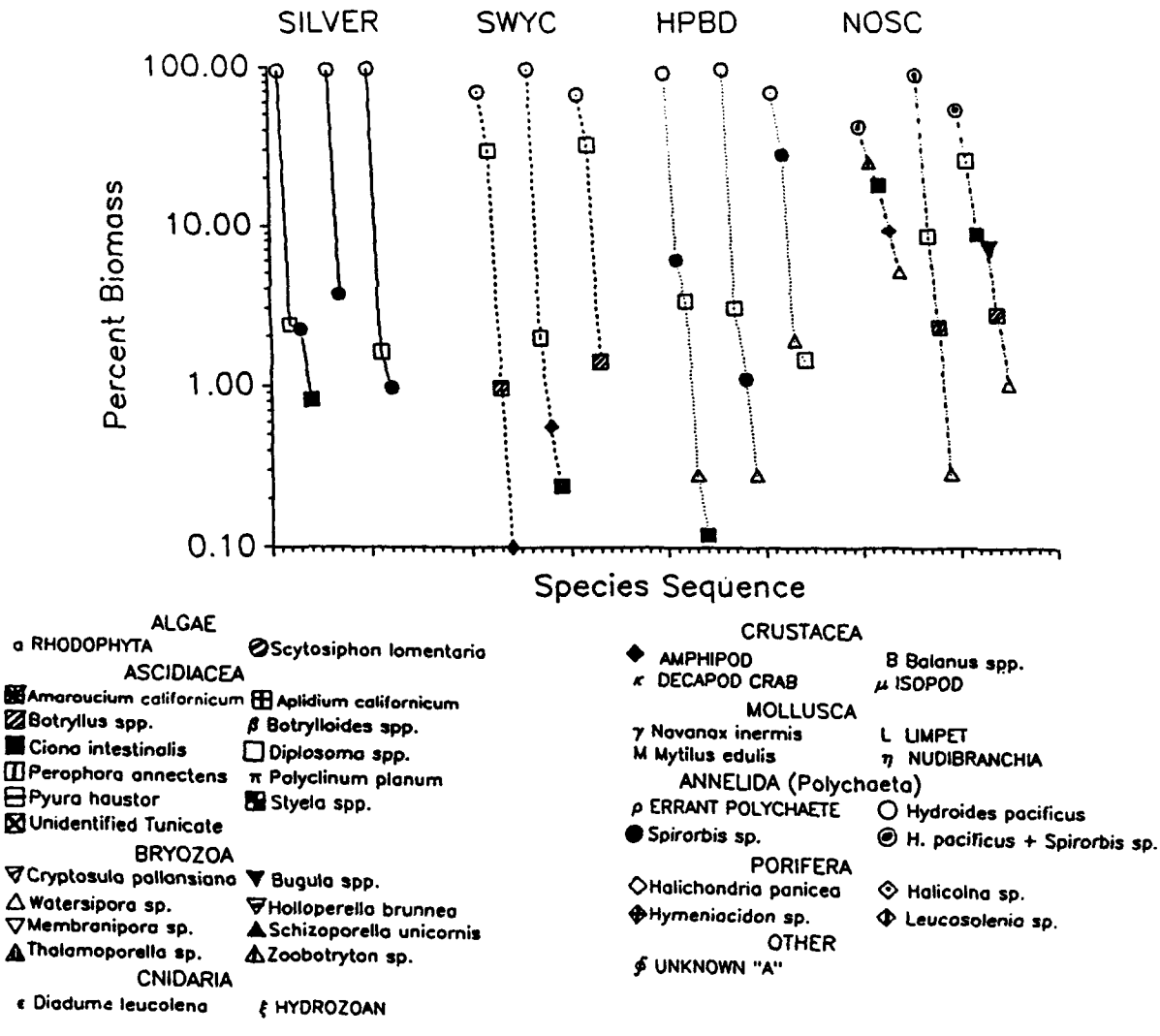


Figure 30. Dominance-diversity curves from replicate panels exposed for 3 weeks from July 29 to August 22 (Days 42 to 63).

Established communities. To measure the structure of natural fouling communities occurring at the stations in Shelter Island Yacht Basin, data were collected from samples of established fouling communities growing on the bottom of docks at the four stations. These data on the established community structure were used to compare the natural community structure with the community structure observed on the fouling panels. The short-term variability in settlement and colonization of fouling panels would be replaced by the long-term exposure to settlement and colonization of the natural communities. The established communities also provide a measure of the community's long-term response to water quality conditions in the yacht harbor.

For the summer samples, the serpulid polychaete worms *Hydroides pacificus* and *Spirorbis* sp. were the most dominant taxa at the Silvergate, Harbor Police, and Southwestern stations, comprising 90.2%, 77.2%, and 74.4% of the mean biomass, respectively. The mean biomass of the tunicates *Styela plicata*, *Pyura haustor*, and *Botryllus* sp. ranged from 4.5 to 0.2% of the mean biomass for the Silvergate station and 10.8 to 0.1% of the mean biomass at the Southwestern station. Similar abundance and dominance by *H. pacificus* and *Spirorbis* were also present in the winter samples (figures 31 and 32, table 9).

The data from summer and winter samples at the Silvergate station were dominated by serpulid worms, which comprised 84.6% and 82.7% of the mean biomass for summer and winter, respectively. More ascidian species were sampled during the summer than during the winter, and the winter samples had more sponge species present (figure 32).

The replicate samples collected from the Southwestern station were dominated by *H. pacificus* and *Spirorbis* sp. during the summer (77.2% of the mean biomass). However, the winter samples from the Southwestern station were characterized by the codominance of serpulids and the ascidians *Ciona intestinalis* (20.4% of mean biomass) and *Styela montereyensis* (15.5% of mean biomass). Also present were the sponges *Hymeniacidon* sp., *Haliclona* sp., and *Halichondria panicea*, which comprised 10.7%, 5.1%, and 2.4% of the mean biomass, respectively. Nineteen species were identified in the winter samples collected at the Southwestern station, compared to only 10 species collected in the sample taken in the summer (figure 32).

Both the summer and winter samples of established communities at the Harbor Police station were dominated by two serpulids polychaetes (*H. pacificus* and *Spirorbis* sp.). These accounted for 74.0% of the mean biomass for the summer samples and 70.3% of the mean biomass for the winter samples. The bryozoan species *Watersipora* cf. *arcuata* comprised 4.0% of the mean summer biomass and 3.6% of the mean winter biomass, while *Bugula neritina* accounted for only 0.4% of the mean biomass for the summer, but 5.7% of the winter biomass. Twenty taxa were identified in the winter samples compared to only ten taxa in the summer samples. The increased number of species accounts for the more "S-shaped" dominance diversity curves obtained for the winter data (figure 32).

The established species assemblages sampled at the NOSC station during the winter, differed markedly from that of the other stations. The barnacles *Balanus* spp. (*B. amphitrite*, *B. glandula*, and *B. tintinnabulum californica*) and the mussel *Mytilus edulis* accounted for 52.4% and 29.7% of the mean biomass, respectively, while *Spirorbis* sp. and *H. pacificus* only comprised 0.2% and 0.03% of the biomass, respectively (figure 32). The bryozoan species, which comprised 9.8% of the mean biomass at the NOSC station, included (in decreasing order of abundance) *Holoporella brunnea*, *Watersipora* cf. *arcuata*, *Zoobotryon verticillatum*, and *Bugula neritina*. Eighteen taxa were identified in the samples from the NOSC station (figure 32).

The general shape of the dominance-diversity curves obtained with data from the established community samples are similar to the dominance-diversity curves obtained from the settling panel data.

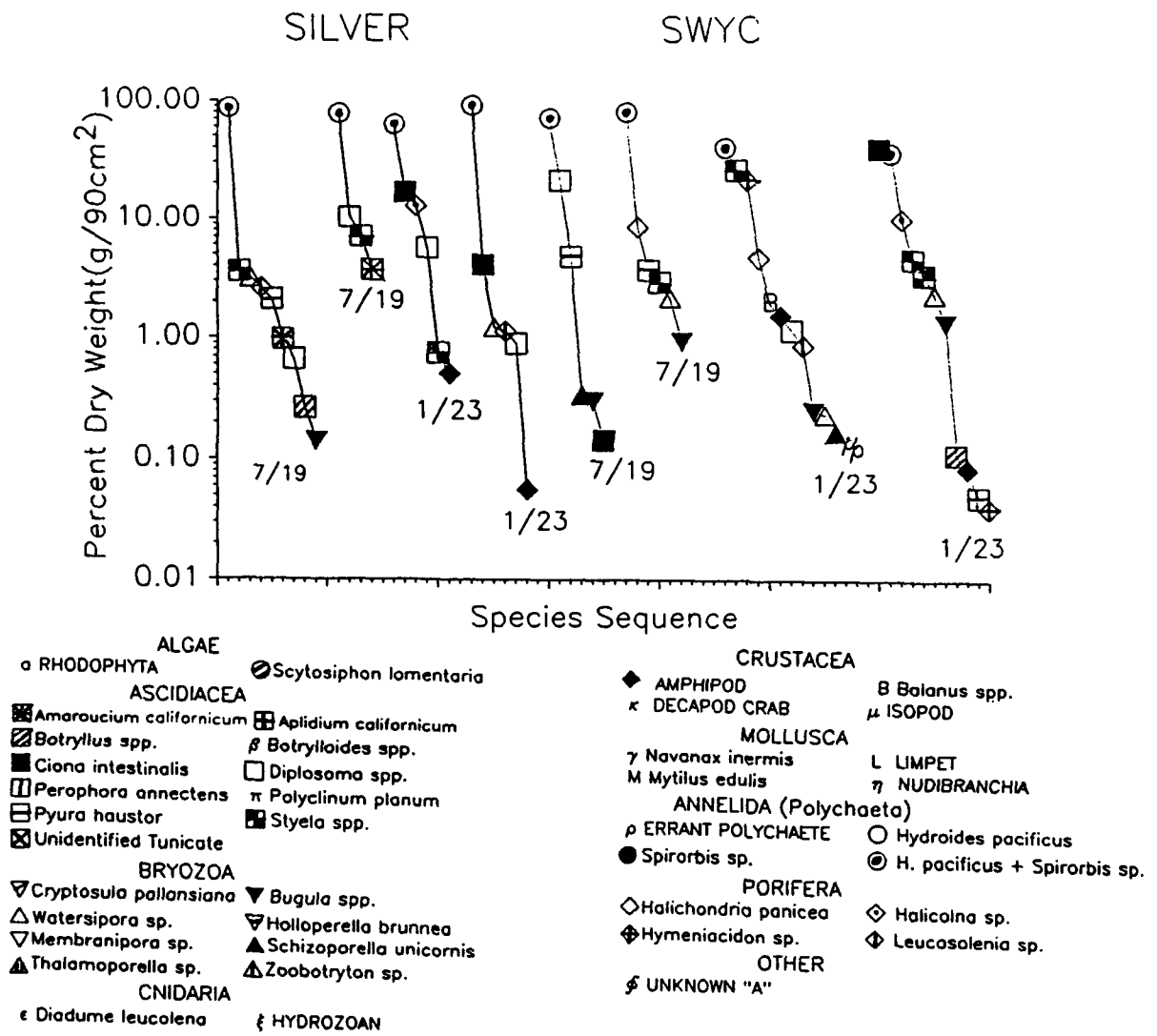


Figure 31. Community structure sampled from established fouling communities on July 19, 1986, and August 22, 1987, at the Silvergate and Southwestern stations.

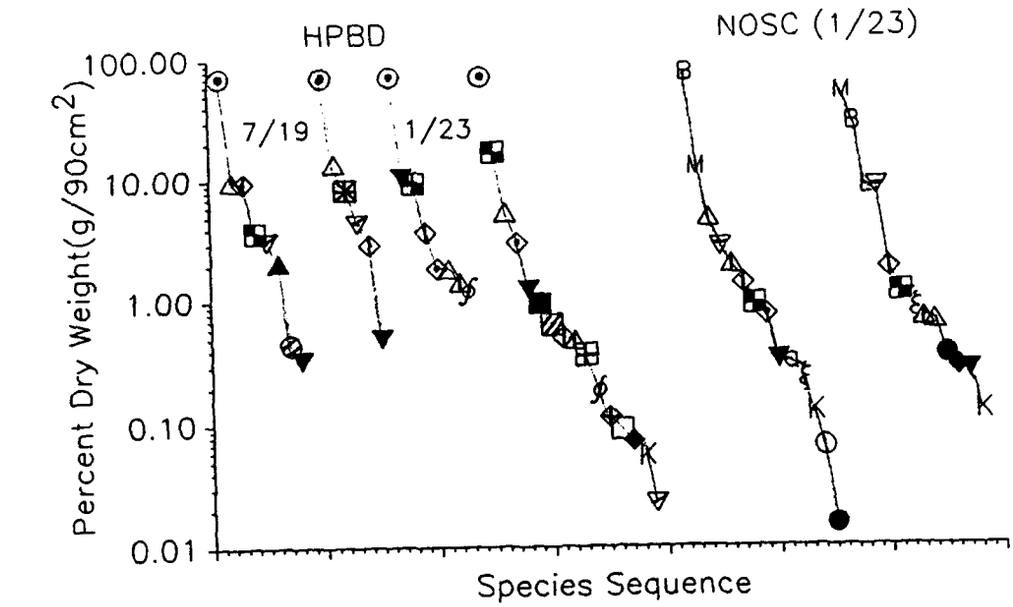


Figure 32. Community structure sampled from established fouling communities at the Harbor Police and NOSC stations.

The curves obtained from data at the NOSC and Harbor Police stations were more curvilinear than those obtained from the Silvergate and Southwestern stations, which exhibited straighter geometric series. More curvature in the dominance-diversity curves reflects higher species richness and diversity in the community.

The plots of community composition of the established fouling communities suggest that community responses to the pollution gradient are very similar to those observed in the samples obtained from the settling panels. The samples from the natural community at the NOSC station were dominated by *Balanus* spp. and *Mytilus edulis*, which are well recognized dominant species in the intertidal waters of California (Ricketts et al., 1985; Reish, 1972). The reason *Balanus* and *Mytilus* were not sampled on the panels was probably because *Balanus* and *Mytilus* larvae were not abundant during the time the panels were exposed or because the panels were not exposed long enough for *Balanus* and *Mytilus* to colonize. Another reason could be that the panels did not provide suitable substrate for *Balanus* and *Mytilus* larvae. The presence of these dominant species in the established community suggests that over long time periods and in the absence of high levels of pollution, these species are able to colonize successfully.

MICROCOSM EXPERIMENT

Settlement and growth of fouling organisms on the panels in the microcosm tanks were very limited compared to that which occurred on the panels exposed in the bay off the adjacent dock. This result suggests that there was a very strong "apparatus effect" within the microcosm. The biomass density on the dock panels exposed in the bay was 66 times higher than the biomass density on panels exposed to ambient bay water in the control tanks (table 14). The concentration of TBT in the control tanks and in the ambient bay water was the same (mean of 0.006 µg/l TBT).

Taxa with biomass densities greater than 0.1 g/50 cm^2 sampled on the dock panels included tunicates (*Ciona intestinalis* and *Diplosoma* sp.), brown algae (*Scytosiphon lomentaria*), and bryozoans (*Schizoporella* sp. and *Membranipora* sp.) (table 14B). The dock panels also yielded biomass densities greater than 0.01 g/50 cm^2 for crabs (*Lophopanopeus* sp. and *Pinnixa* sp.), the mussel (*Mytilus edulis*), tunicates (*Perophora annectens* and *Pyura haustor*), and filamentous red algae (Family *Ceramiaceae*) (table 14). These species were not present in any appreciable numbers on the panels exposed in the microcosm, which were colonized only by a few species, such as the polychaete *Spirorbis* sp., assorted amphipods (gammarids and caprellids), and filamentous brown algae which formed a mat over the surface of the panels.

The only data obtained from the microcosm panels were biomass density (g/500 cm^2), biomass of the algal mat (g/50 cm^2), biomass of *Spirorbis* sp. (g/50 cm^2), and biomass of crustacean species (g/50 cm^2) (table 14A). There were no significant differences between treatments for biomass density, algal mat biomass, *Spirorbis* sp. biomass, amphipod biomass, or other species biomass (table 14A). In contrast, data obtained from the dock panels exposed in the bay were settled and colonized by many species (table 14B).

Table 14. (A) Means and results from analysis of variance for biological data obtained from panels exposed in the microcosm tanks. (B) Species names and mean biomass collected from panels exposed off of the adjacent dock.

(A) Microcosm Panels

		Treatments				
Variable	Units	Control	10%	25%	100%	P
Biomass	g/500 cm^2	0.35	0.38	0.69	0.55	NS
Algal mat	g/50 cm^2	0.04	0.05	0.06	0.08	NS
Amphipod	g/50 cm^2	0.001	0.001	0.003	0.005	NS
Spirorbis sp.	g/50 cm^2	0.14	0.006	0.01	0.005	NS

(B) Dock Panels

Taxa or species	Mean Biomass g/50 cm^2
Family Ceramiaceae	0.030
Scytosiphon lomentaria	0.617
Leucosolenia sp.	0.009
Family Serpulidae	0.009
Mytilus edulis	0.045
Lophopanopeus sp.	0.066
Hippodiplosia americana	0.004
Membranipora sp.	0.218
Schizoporella unicornis	0.345
Botrylloides spp.	0.003
Ciona intestinalis	0.701
Diplosoma spp.	0.490
Perophora annectens	0.003
Pyura haustor	0.018
Styela spp.	0.002

DISCUSSION

ENVIRONMENTAL GRADIENT

An environmental gradient consists of many variables which interact to create specialized conditions for organisms to adapt and exploit. The environmental gradient within Shelter Island Yacht Basin had components consisting of physical mixing variables and water quality variables including toxic chemical compounds. Organotin compounds and copper concentrations were measured during this study, but other pollutants undoubtedly were part of the pollution gradient. Additional pollutants probably include other heavy metals like zinc and cadmium, oil and grease from vessels, by-products of fuel combustion, sewage from boats, and runoff from the shore. It can be assumed that other toxic compounds would be present in amounts proportional to the copper and organotin concentrations because other toxicants would be from similar sources and would be subjected to the same mixing dynamics present in the yacht basin (Zirino et al., 1978; Young et al., 1979).

Copper Gradient

Copper concentrations were significantly higher inside the yacht basin. At the stations with the highest concentrations of copper, the variability was lower than the stations with lower levels of copper (table 5). On the average, copper levels measured at stations within the yacht basin were about four times higher than the levels measured at the NOSC station.

Other studies have reported similar distributions of copper concentrations in the Shelter Island Yacht Basin (Zirino et al., 1978; Lane, 1980). An anodic stripping voltammetry (ASV) derived copper concentration of 6.4 µg/l was reported for a station located between NOSC and the Harbor Police boat dock at the Scripps Marine Physical Laboratory pier (Zirino et al., 1978). Other ASV data showed that the copper concentration within Shelter Island Yacht Basin was eight times higher than the copper level measured in the main channel of the bay (Zirino et al., 1978). Tidal variations of copper and zinc were measured on May 5 and 6, 1975 (Zirino et al., 1978), and tidal variations of lead, cadmium, and zinc were measured on September 29 and 30, 1975 (Kenis et al., 1978). These studies showed that the concentrations of copper and zinc increased at low tide and decreased during high tide because of the influx of cleaner ocean water during incoming tide.

Dissolved and particulate copper concentrations in San Diego Bay were monitored from July 1978 to June 1979 using ASV to determine dissolved copper and filtration and x-ray fluorescence spectrophotometry to measure particulate copper (Lane, 1980). Copper concentrations measured at a station within Shelter Island Yacht Basin averaged 6.05 µg/l (range of 0.9 to 17.9 µg/l, with a coefficient of variation (CV) of 63%) and 8.19 µg/l (range of 1.7 to 19.1 µg/l, CV=50%) for dissolved and total copper, respectively. In comparison, dissolved copper concentrations measured at the station in the main channel and at a station located at the Naval Station at 32d Street averaged 1.7 and 4.9 µg/l, respectively. There was about twice as much variability in the data obtained from the main channel and the 32d Street stations, which had a coefficient of variation for dissolved copper of 90% and 88%, respectively. These data are comparable to the copper data reported in this study, which showed that the copper concentrations inside Shelter Island Yacht Basin were higher and less variable than the lower, more variable concentrations measured in the main channel of San Diego Bay. This suggests that with respect to copper concentrations the environment within the yacht basin was more stressful, while the environment in the main channel of the bay was less stressful but more unpredictable due to higher variability in copper concentrations.

The data from the present study suggest that most of the copper present was in a dissolved or labile state, rather than in particulate matter. Evidence for this conclusion is based on the levels of

copper determined by ASV and ICP. One would expect copper determined by ICP to represent "total copper" and copper determined by ASV to represent "dissolved or labile copper"; therefore, the copper analyzed by ASV should be a subset of the copper analyzed by ICP. The mean copper concentration determined by ICP was higher than the mean copper concentration determined by ASV for the NOSC and Southwestern stations, about equal at the Silvergate station, and lower at the Harbor Police station. The data obtained by the ASV method were almost twice as variable as that from the ICP analysis (figure 8). This variability was due to copper concentrations that were too high to be measured effectively by ASV. The ASV method is optimal for copper at concentrations between 10^{-8} molar and 10^{-7} molar, which was exceeded by some of the samples collected in the yacht basin (Zirino, 1981). Concentrations of copper above 2.5×10^{-7} (15 µg/l) would not be able to reach equilibrium with the mercury drop electrode during the plating time used for the analysis (A. Zirino, personal communication).

The cupric ion (Cu^{2+}) electrode response measured with the Marine Environmental Survey Craft (MESC) system indicates there was a distinct copper gradient from the main channel into the yacht basin. Discrete samples taken during the MESC survey showed that the copper concentration from the entrance to within the yacht basin increased by about 35% during incoming tide (ASV—6.0 to 9.0 µg/l and ICP—7.5 to 11.0 µg/l) and about 70% during outgoing tide (ASV—2.0 to 8 µg/l and ICP—4.5 to 12 µg/l). The discrete samples support the evidence that the copper electrodes were actually detecting the copper gradient (figures 19 and 20).

Other studies have shown direct relationships between the Cu^{2+} electrode response and copper concentrations determined by other methods (Zirino and Selgiman, 1981; Johnston et al., 1986). However, complexation capacity and the presence of organic ligands can interfere and mask the copper electrodes' ability to directly measure the copper present. In the least, the Cu^{2+} electrode is useful as an indicator of increased copper activity, which is more biologically important to marine organisms than the actual concentration of copper (Sunda and Guillard, 1976).

Organotin Gradient

Concentrations of organotin compounds were increased at stations located inside the yacht basin and had lower variability between samples than the station at NOSC (figure 8). The average concentrations of tributyltin (TBT) and dibutyltin (DBT) were about 9 and 10 times higher inside the yacht basin than at the entrance, while the concentration of monobutyltin (MBT) was only about 4 times higher inside the yacht basin.

Other studies have shown a similar pattern of organotin concentrations in Shelter Island Yacht Basin. Organotin concentrations at two stations in Shelter Island Yacht Basin had mean TBT concentrations of 0.704 and 0.2313 µg/l, respectively (Seligman et al., 1986a). The station with the lower, more variable concentration of TBT was closer to the mouth of the channel (near the Harbor Police boat dock station used in this study), while the higher less variable concentration was inside the yacht basin (near the Southwestern Yacht Club station used in this study) (Seligman et al., 1986a). Significant differences between station location, depth, and tidal conditions, as well as significant interactions between station location and tide and station location and depth of the samples analyzed were also found (Seligman et al., 1986a). Another study (Grovhoug and Seligman, 1986), reported a mean of 0.247 µg/l of TBT with a range between 0.187 to 0.350 µg/l for Shelter Island Basin samples. This range of TBT concentrations is comparable to the data obtained for the stations located within the basin during this study (figure 8).

Flushing and tidal mixing undoubtedly determine the organotin gradient. Evidence indicates that hydrography at a given location is more important in determining organotin concentrations than

sources and sinks of organotins (Seligman et al., 1986a). As much as 20-fold variations in TBT concentrations (0.017 to 0.332 µg/l) have been reported at the NOSC pier during a tidal cycle (Clavell et al., 1986). Even in the sediments where tidal variability would be dampened, concentrations of butyltins were lower where flushing was high and higher where flushing was low (Stang and Seligman, 1986).

TBT degrades into less toxic DBT and MBT as a result of biological degradation by microbes (Seligman et al., 1986b). Speciation of butyltins determined from measurement of ^{14}C-labeled TBT showed that the half-life of TBT in Shelter Island Yacht Basin was 6 to 7 days, and that the principal degradation product was DBT. Results of least squares regression analysis showed that on average about 60 to 50% of the total butyltin species consisted of TBT, while DBT accounted for 30 to 40% and MBT about 10% of the total butyltin species (Seligman et al., 1986a; Seligman et al., 1986b). The data from the present study (table 6) show that the ratio of butyltin species was at about the same percentages. The higher percentages of DBT species at stations with higher concentrations of TBT (table 6) show that faster degradation rates were present at the stations with higher concentrations of TBT (figure 8).

Other Gradients Present

The differences between temperature, pH, and dissolved oxygen measured during the field monitoring in Shelter Island Yacht Basin varied by less than 6% between the stations. This result suggests that these variables were more homogeneous in their distribution in the yacht basin than the toxic chemical compounds. However, significant differences between stations for temperature, pH, dissolved oxygen, salinity, turbidity, and chlorophyll recorded by the Marine Environmental Survey Craft (MESC) indicate that the environmental variables were not constant and would contribute to the environmental gradient present in the yacht basin.

Data from the MESC system showed that water quality characteristics changed over the tidal cycle. The MESC system was able to delineate patches of water with distinct characteristics which moved in and out of the yacht basin during changing tides. For example, during outgoing tide the water present at the entrance to the yacht basin was cooler and more saline than during incoming tide (figures 17 and 19). However, temperature and salinity remained relatively constant in the inner portions of the yacht basin, suggesting that the waters within were not as regularly flushed and would, therefore, have a longer residence time in the yacht basin. These factors indicate that the environment within the yacht basin was more constant than the more dynamic environment present at the entrance of the yacht basin.

The large number of significant correlations obtained between the water quality variables was due in part to the large sample size ($n>250$) and degrees of freedom used in the correlation analysis. Even so, the high correlations obtained for both incoming and outgoing tide and over the spatial area of the yacht basin show that the distribution and variance of the environmental variables are linked (table 7). The high degree of correlations between environmental variables requires methods capable of quantifying the the natural variability of the system (Gadbois, 1984; Gadbois and Neilson, 1984; Tagatz et al., 1986; Gilbert, 1987).

Variability of Gradients

The gradient characterized by the toxic chemical concentrations within the Shelter Island Yacht Basin showed highest variability, with respect to sample date and tidal state, in copper and organotin compounds at the NOSC and Harbor Police boat dock stations. However, the mean concentrations of

these toxic pollutants were lowest at the NOSC station. Even though organisms growing on the NOSC pier were subjected to spikes of increased toxic chemical concentrations, which appeared to be unpredictable, on the average the concentrations at the NOSC station were significantly lower and therefore less stressful, as evidenced by the increase in species richness, than those observed at the Silvergate Yacht Club (Silvergate) or Southwestern Yacht Club (Southwestern) stations located well inside the Shelter Island Yacht Basin (figure 1). The concentrations of pollutants were more stable at the Silvergate and Southwestern stations and, therefore, more constant but at significantly higher concentrations. This condition undoubtedly subjected the marine organisms living in these areas to higher stress.

The analysis of variance applied to these data partitioned the variability into station effects, day effects, and tidal effects. Significant differences between station and day can be attributed to periodic and inherent variability of the system caused by the tidal and mixing processes of the system. The inherent temporal variability of the system contains both a long-term component (figure 5A) and a short-term component (figures 5B to 6I). The data show the high variability which can be attributed primarily to tidal changes and variation between sampling days. For example, more variation in copper (figures 9 and 10) and organotin concentrations (figures 11 to 13) was evident for days during neap tides than during spring tides. Less magnitude in tide heights during neap tides (days 0, 10, and 42—figure 5) than during spring tides (days 21, 31, 52, and 63—figure 5) could explain some of the differences observed in variability between sample days.

The differences in the toxic chemical concentrations during spring and neap tides may be explained by the fact that during spring tides there are greater water masses being moved by tidal forces. These create stronger currents and a greater flushing action, resulting in a more homogeneous mixture of water in the yacht basin. During neap tides there is less tidal pumping and less movement of water. The reduced flushing in the yacht basin could allow patches of water with distinct hydrographic features to maintain their identity and which could result in a more heterogeneous distribution of physical and chemical variables within the yacht basin. The result would be higher variability in chemical measurements.

Some variability could have been produced by inaccuracies in sampling and laboratory analysis. Even though there was little difference between the means of the physical variables, the ANOVA detected differences between stations for temperature. Part of these differences may be caused by time differences between the collection of the samples.

Semisynoptic sampling using the MESC system was performed to control the temporal variability of the system. The variability recorded during the MESC transects provides a measure of the spatial variability of water quality variables within the yacht basin. The sampling intervals of 10 days for water chemistry samples and 3-week and 9-week samples of fouling panels were used in this study to account for the natural variability of the system. The sampling was designed in this manner to average out the inherent variability components associated with diurnal and lunar cycles (figure 5).

COMMUNITY RESPONSE TO ENVIRONMENTAL GRADIENTS

Fouling Community Response

The main impact of pollution on the development of fouling communities would be the reduction of larvae available for settlement and colonization. Colonization and community development are dependent on the abundance of settling larvae, which in turn is determined by both seasonal changes and the organisms that have already settled on the surface (Osman, 1977). The colonization process

can be described as "open ended" because the outcome is highly variable, subject to seasonality, affected by disturbance, and dependent on the history of the surface being colonized (Osman, 1977). In general, invertebrate larvae are more sensitive to the effects of pollution than are adults (Epifanio, 1984; Williams et al., 1986; Johnston and Lapota, 1989). Therefore, if larval abundance is reduced in the areas with higher toxic chemical concentrations, the effect would be evident in the colonization patterns measured on the panels exposed in those areas.

Extremely high settlement of *Hydroides pacificus* on the panels at the Southwestern station could have been due to the high abundance of *H. pacificus* adults located at that station. The readily available *H. pacificus* larvae would allow them to opportunistically exploit and colonize available space provided by the panels without threat of inhibitory interactions with other species (Dean and Hurd, 1980). In addition the tubes of established *H. pacificus* would provide suitable habitat for latter *H. pacificus* larval settlement (Dean, 1981), further increasing *H. pacificus* dominance at the Southwestern station. These factors, as well as spatial and temporal variations in larval abundance and distribution, could account for the lack of successional trends in development of fouling communities (Sutherland and Karlson, 1977; Goren, 1979; Chalmer, 1982).

The sessile life-style of fouling organisms makes possible the determination of community endpoints for the analysis of community structure and function. Processes such as respiration per unit biomass and variability in settlement and colonization patterns can be evaluated (Dygert, 1978). In addition, sessile foulers as well as motile species associated with them (amphipods) provide captive organisms for the evaluation of pollution effects on communities of marine organisms. In a study conducted to determine the effect of power plant discharge on marine organisms, fouling community development was used to monitor and identify changes in community structure that were related to increased stress from the thermal effluent (Smith, 1985).

Communities measured on fouling panels provided ecologically relevant information required to determine the effects of pollution (Epifanio, 1984; Long and Chapman, 1985). The pollution would affect the larvae, juveniles (early colonists), as well as adults. The effect of pollution was evaluated under natural conditions of exposure (Salazar, 1986) and with populations which are presumably accustomed or acclimatized to the polluted conditions (Beaumont and Budd, 1984; White and Champ, 1983). The study also related the level of contamination to the biological processes of growth, survival, and reproduction occurring on the panels.

Evaluation of Community Response to Pollution

The specific ecological requirements of a species can be viewed as being in a constant state of flux, resulting in a continuing process of development. Each species requires a successful series of interactions and responses to environmental pressures to survive. No two species can coexist on the same limiting resource; one must win control of the resource, the loser is eliminated or else has to adapt to avoid competition (Slobodkin, 1961; Slobodkin and Sanders, 1969; Gray, 1981; Theiry, 1983). The panel surfaces represent a limiting resource—space—and, thus, provide a measure of at least one dimension of the ecological requirements of the community (Hurlbert, 1981). All fouling organisms require space as a component of their habitat. How space was used by the various species under changing environmental conditions provides an effective means of comparing community structure.

Rates of elimination and immigration are related to the size of the ecological island, and the equilibrium number of taxa is determined by the dynamic interaction between immigration and elimination or extinction. By making comparisons between ecological islands of uniform size (e.g., the

experimental panels used in this study), comparisons of the resulting community structure can be made (Niederlehner et al., 1986).

Marine pollution studies must relate pollution levels to biological consequences to provide a useful assessment. Chemical data provide the measure of contamination, but the biological data are required to show what effect pollution has on the biota (Long and Chapman, 1985; Niederlehner et al., 1986; Tagatz et al., 1986). The effect of contamination on communities is to cause the most sensitive species to be reduced or eliminated altogether. This, in turn, produces a simpler community containing fewer species (Gray, 1981). At the same time, opportunistic species, which can radically increase their abundance in response to an advantage in tolerance to environmental perturbations, can cause the community to be dominated by fewer species (Levin, 1984).

The relationship between statistical significance and biological significance has been discussed (Taub et al., 1986; Tagatz et al., 1986; Niederlehner et al., 1986). When interpreting results, one must reduce the probability of committing a Type I error to correctly interpret whether a statistically significant difference represents a real chemical or biological difference. This requires applying sound principals of experimental design, close inspection of data summaries in graphs and tables, and intuitive knowledge of the system to determine the relevance of the result (Hurlbert, 1984; Taub et al., 1986; Stewart-Oaten et al., 1986). Statistical significance is a function of the number of samples, the statistical test, alpha, and the variance (Taub et al., 1986). Highly variable replicates can mask important differences, while highly uniform data can increase the chance of committing a Type I error when there are no true or chemical or biological effects involved (Tagatz et al., 1986).

The fouling communities described quantitatively for each station represented a sample of the biological response of fouling organisms to the environmental conditions present. The increased species richness at the NOSC station reflects greater success in settlement and early colonization, which probably reflects the fact that the NOSC station is a cleaner environment as far as continued exposure to high pollution levels is concerned. Therefore, a wider variety of species can settle and become established there. Another factor affecting community development could be a function of the disturbance factor (Gray, 1981), such as fish feeding on organisms growing on the panels. The disturbance factor increases the randomness of settlement and affects the amount of biomass variability between the panels. Polychaetes were the dominant species in areas of less variability and higher stress (higher pollution levels). The 9-week fouling panels showed lower variability between panels than did the 3-week fouling panels, as evidenced by the smaller confidence intervals obtained for the 9-week replicates.

The results of the fouling study showed that different patterns of settlement and colonization occurred at the four stations sampled in Shelter Island Yacht Basin. Differences in community structure correlated with distinctly higher concentrations of toxic chemicals measured at stations in the yacht basin. Multiple regression analysis showed that concentration of organotin compounds accounted for a significant portion of variability in species richness, biomass density, polychaete biomass, and ascidian biomass. The relationship was negative for species richness and bryozoan biomass and positive for polychaete biomass and biomass density.

The principal component analysis (PCA) created predictor vectors from linear combinations of the independent variables. The results obtained from regression analysis of these predictor vectors and the dependent biological variables were useful in evaluating the biological response to the environmental conditions in the yacht basin. The toxic chemical vector was more effective in predicting species richness and bryozoan biomass for both the 9-week and 3-week data sets and polychaete biomass in the 9-week data set. This gives strong evidence that the toxic chemical gradient was more important in determining biomass abundance than the physical gradient. Species richness and bryozoan abundance decreased as the toxic chemical vector increased in magnitude (figures 22A, 22D, 23A, and 25D),

which indicates a linear response. However, biomass density and polychaete biomass exhibited a nonlinear response to the toxic chemical vector (figures 22B, 22C, 23B, and 24C).

The species associations developing on the 9-week panels showed there were differences in the community structure associated with increasing levels of copper and organotin compounds. The communities of organisms associated with the lowest levels of pollutants were characterized by the codominance of the bryozoan *Bugula neritina* and the tube-building polychaete worms *Hydroides pacificus* and *Spirorbis* sp. They also had a greater number of species and exhibited more "S-shaped" dominance-diversity curves. The communities associated with higher levels of pollutants were strongly dominated by the polychaetes, had less species, and exhibited straighter dominance-diversity curves, suggesting geometric series. In general, biomass density of fouling organisms increased as the levels of pollution increased, except at the highest levels of pollution, where total biomass was reduced. This reduction suggests a nonlinear relationship between biomass and pollution levels.

Panels exposed for 3-week periods had higher variability than those exposed for 9 weeks, but had similar patterns of settlement and colonization which also coincided with the gradient of toxic chemicals. The community composition measured on 3-week panels exposed to the lowest levels of pollution were characterized by the settlement of more species, increased presence of bryozoan species, and the decreased dominance of polychaetes. Biomass density sampled was also lower at stations with low levels of pollution and high at stations where higher levels of toxic chemicals were measured. There was a correlation between the toxic chemical gradient and the abundance and distribution of species, but it was not as strong as was the correlation obtained for the 9-week data set. The 3-week data set reflects the dynamics of the shorter time scale of measurement.

The community composition measured from the established communities suggests that natural communities also respond to the presence of toxic chemicals. Communities sampled at the higher levels of pollution were dominated by two polychaete tube worms (*H. pacificus* and *Spirorbis* sp.), had fewer species, and exhibited straighter dominance-diversity curves than did those sampled at the lower levels of toxic chemicals. Communities sampled at the lower levels of pollution were dominated by longer lived species, including barnacles of the genus *Balanus* and the mussel *Mytilus edulis*.

Dominance-Diversity Curves and Pollution

The dominance-diversity curves show there were distinct species assemblages present at the stations. These differences are no doubt due to the chemical, physical, and biological differences between the stations. The response of each species to the environmental gradient is dependent on its life history traits such as timing of reproduction, mode of development, mobility, and dispersal methods (Levin, 1984). The amount of biomass present on the fouling panels, therefore, will be a measure of how successful or unsuccessful a certain species was in responding to the environmental gradient present.

The use of biomass as a measure of abundance provides the biological basis required for quantitative comparisons between communities (Whittaker, 1965; Hurlbert, 1971; Gray, 1981; Washington, 1984). The biomass data presented as dominance-diversity curves show community patterns which are a result of "competition and differentiation along the spatial gradient of the environment" (Whittaker, 1969, p. 182). Therefore, the relative success of fouling organisms, in converting external energy into local biomass, is a function of species interactions and adaptations to the physical environment. These processes result in specific community structure which may be expressed by the shape of its dominance-diversity or importance-value curve (Whittaker, 1965, 1969).

The differences in the shapes of the dominance-diversity are due to events influencing an individual panel, thereby affecting the colonization pattern that unfolds. The colonization patterns are a

response to natural processes, such as larval settlement, species interactions of competition and predation, and physical disturbances occurring at the panel surface (e.g., fish feeding on fouling organisms).

The polychaetes were most strikingly dominant on the panels from the Southwestern Yacht Club and Silvergate Yacht Club stations and could be considered important. But importance of a particular species in a community is dependent on the role of that species in the community. Some species, such as *Scytosiphon lomentaria* and some of the branching bryozoans (*Bugula* spp.), provided additional habitat features exploited by other species, such as gammarid amphipods (figure 27). Simple abundance does not necessarily imply importance. Productivity alone does not imply importance. Importance is defined as the change in productivity that would occur if the species were removed (Hurlbert, 1971).

Functional groups are groups of species which perform the same function, with respect to their life history traits, in a community. Therefore, communities could be functionally identical, yet have completely different groups of species present. Examples of functional groups sampled from the Shelter Island Yacht Basin community are suspension feeders specialized to filter specific sized particles (like the polychaetes and species of stalked bryozoans); motile and predacious organisms (errant polychaetes, nudibranchs, and crabs); encrusting organisms requiring unobstructed space (encrusting bryozoans—*Watersipora* spp., sponges, and some tunicates—*Botryllus* spp.); and slime organisms not requiring unobstructed space (tunicates—*Diplosoma* spp. and *Ciona intestinalis*).

Dry weight biomass provides a more meaningful and directly comparable measure for contrasting fouling communities than does the number of individuals. Dry weight biomass measurements are also less susceptible to error than measures of percent cover and numbers of individuals, particularly when dealing with sessile forms such as ascidians and sponges. Also the twisting, entangling growth of marine foulers renders percent cover data both difficult to obtain and difficult to interpret. Dry weight biomass represents a direct measure of the space requirements of a species. However, biomass measurements are not without error. A possible source of error was the fact that relatively higher biomass measurements were obtained for organisms with calcareous tests, such as the polychaetes and barnacles, and relatively lower biomass measurements were obtained for soft bodied organisms such as tunicates and sponges. Yet the calcareous tubes are as much part of the space occupied by those species as are the shells of bivalves, and, therefore, adequately represent use of the habitat by those species.

Biomass is a good measure of importance, because even if all species present are not sampled adequately, the species that are difficult to sample because of low biomass will not significantly change the shape of the curve (Whittaker, 1965; S. Hurlbert, San Diego State University, personal communication). Although sampling error can affect the individual points, they will not affect the overall shape of the curve (Whittaker, 1965). The biomass measure also eliminates discrepancies, encountered by measures such as percent cover, caused by organisms growing upright and attached by small holdfasts (Dygert, 1978) and complications arising from overgrowth interactions (Buss, 1979).

Based on the assumption that the fraction of resources used by a species will be "closely related" to the amount of space occupied, the amount of biomass produced reflects the fraction of the available space, as defined by the ecological island provided by the panel, used by the species. The biomass produced will be the net result of interactions between and within species as well as adaptation to physical constraints present at the surface of the settling panel. The amount of biomass produced will be a function of important biological processes of reproduction, growth, and survival. By using dominance-diversity classifications of fouling communities (Whittaker, 1969; Lambshead et al., 1983; Warwick, 1986), comparisons can be made between communities on a direct biological basis.

EVALUATION OF MICROCOSM EXPERIMENT

The microcosm system, while effective in delivering treatment concentrations of TBT in a controlled environment, was not effective in determining the response of fouling communities to increased levels of TBT due to the lack of colonization on panels in the tanks relative to the colonization on panels in the bay.

The purpose of the microcosm experiment was to control the natural spatial and temporal variability by making the environmental conditions within each tank similar and varying the organotin concentration to determine its effect on the composition of fouling communities. The major conclusion from the microcosm study is there was a significant "apparatus" effect. The lack of settlement on the microcosm panels, compared to the relatively high settlement and colonization sampled on panels exposed in the bay, could have been caused by a combination of the following factors:

1. One problem may have been the lack of larval material and food due to an inadequate flow rate of seawater supplied to the tanks. If the flow rate was not sufficient, larval material would settle out before reaching the tanks, and food material for settled individuals would be in short supply within the tanks. Other workers have shown that flow rate is critical to the stability of microcosm systems and their ability to function properly (Henderson, 1985; Grassle and Grassle, 1986; Salazar and Salazar, 1987; Salazar et al., 1987b).

2. Another factor may have been there were too many other organisms in the tanks. The microcosm experiment took place during Phase 1 of an evaluation of the portable environmental test system (PETS), which required additional organisms to be placed in the microcosm tanks. Initially, each tank contained 35 scallops (*Hinnites multirugosus*), 120 clams (*Macoma nasuta*) placed in twelve 10.16-cm by 15.24-cm by 15.24-cm deep plastic sediment trays, 120 mussels (*M. edulis*) suspended in 12 meshed racks, 6 panels with precolonized fouling communities from 126 days of exposure in the bay off of the dock, and 6 bare panels, 3 of which were for my experiment (Salazar et al., 1987a, 1987b). The food requirements of these filter feeding species were obviously very high, and these larger, established animals may have consumed most of the larvae before settlement. For those larvae that did settle, lack of an adequate food supply may have caused poor growth and survival. Direct evidence for this mechanism is reported in Salazar et al. (1987b). Their data show increased mussel growth during Phase 2 of the PETS test and evaluation, when total tank biomass was reduced (Salazar et al., 1987b).

3. The larvae of fouling organisms could have been damaged or killed by the impellors of the seawater pump system. The PETS employed centrifugal swimming pool pumps to supply water to the tanks. However, there was settlement of three bivalve mollusc species (*Ostraea lurida*, *M. edulis*, and *Musculista senhousia*) inside the seawater distribution lines (Salazar et al., 1987b).

4. The pumping system drew water from the bay in such a manner that recruitment could have been affected. The intake lines were 15.24 cm in diameter and were located at a fixed position 3 m below the surface on a floating dock. Current patterns from the pumping could have reduced the amount of plankton available to be delivered into the microcosm tanks. Problems with zooplankton avoiding the intakes of other pumping systems have been considered (Lapota and Losee, 1984; Lapota et al., 1988).

The microcosm did create a gradient of organotin compounds and provided replicate measures of the treatments, since each treatment was a replicate dose of the toxicant from the same source. However, the microcosm system introduced stress not present in the natural environment. It could be assumed that the same amount of stress was present in all the tanks allowing valid comparisons between treatment effects of increased TBT concentrations. It appeared that the increased stress and interference on settlement, caused by the microcosm system, effectively masked the ability to resolve differences in biological effects between the treatments.

Improvements could be made to the microcosm system by modifying the plumbing and delivery system (Salazar et al., 1987b; Henderson, 1988) and by conducting only compatible experiments in parallel. That is, a study attempting to elucidate community dynamics should not be run in the same tanks as a bioassay or bioaccumulation study. The presence of additional species, not recruited, is essentially another treatment which masks the effects from the desired treatment and makes interpretation of the results difficult.

CONCLUSIONS

1. Copper and organotin compounds were significantly higher at the stations inside Shelter Island Yacht Basin. The concentrations of copper increased by about a factor of 4, TBT concentrations increased by about a factor of 9, DBT concentrations increased by a factor of almost 10, and MBT concentrations increased by a factor of 4 between the stations with the lowest and highest levels of pollution.

2. Most of the copper measured was present in dissolved or labile form, suggesting that copper was biologically available to the marine organisms in the yacht basin. There was a constant proportion of organotin species, suggesting that degradation of TBT to DBT and MBT was relatively constant and in proportion to the concentration of TBT present.

3. Differences in community composition along the pollution gradient were identified with the following characteristics. At the lowest levels of pollution, the community had greater species richness and more "S-shaped" dominance-diversity curves and were dominated by the bryozoan *Bugula neritina* and the tube building polychaete worms *Hydroides pacificus* and *Spirorbis* sp. At higher levels of pollution, the communities had less species richness and straighter dominance-diversity curves suggesting geometric series and were strongly dominated by the polychaetes *Hydroides pacificus* and *Spirorbis* sp. Biomass density increased as levels of copper and organotin increased, except at the highest levels of copper and organotin. At these highest levels biomass density decreased, suggesting a nonlinear relationship between biomass and pollution levels.

4. The polychaetes *H. pacificus* and *Spirorbis* cf. *spirillum* were the most successful species in the more polluted ares, followed by ascidian species including *Diplosoma macdonaldi* and *D. pizoni*, *Botryllus* sp., and *Ciona intestinalis*. The bryozoan *Bugula neritina* was more successful in areas of lower pollution levels.

5. The microcosm was not effective in determining differences in settlement and colonization of fouling organisms on experimental panels because the apparatus' effect was too great.

6. Differences in marine fouling communities measured in the field at increasing levels of pollution can give an indication of the ecological effects of pollution. Successful demonstration of settling and colonization differences in the microcosm system would provide a valuable confirmation of the impact observed in the field data.

REFERENCES

Andrew, R. W. 1977. "Effects of inorganic complexing on toxicity of copper to *Daphnia magna*." *Water Resour.* Vol. 11, pp. 309-315.

Beaumont, A. R., and M. D. Budd. 1984. "High mortality of the larvae of the common mussel at low concentration of tributyltin." *Mar. Pollut. Bull.* Vol. 15, No. 11, pp. 402-405.

Borgman, U., and K. M. Ralph. 1984. "Copper complexation and toxicity to freshwater zooplankton." *Arch. Environ. Contam. Toxicol.*, Vol. 13, pp. 403-412.

Bower, D. R., and S. H. Lieberman. 1985. "Multi-computer acquisition and processing for marine environmental monitoring." In, *Ocean Engineering and the Environment, Conference Record of Oceans '85*, Marine Technology Society, Washington, District of Columbia, pp. 234-241.

Boyle, E. A. 1979. "Copper in natural waters." In, *Copper in the Environment Part I: Ecological Cycling*, edited by J. O. Nriagu, Wiley, New York, New York, pp. 77-86.

Boyle, E., and J. M. Edmond. 1975. "Copper in surface waters south of New Zealand." *Nat.* Vol. 253, pp. 107-109.

Buss, L. W. 1979. "Bryozoan overgrowth interactions—the interdependence of competition for space and food." *Nat.*, Vol. 281, pp. 475-477.

Chalmer, P. N. 1982. "Settlement patterns of species in a marine fouling community and some mechanisms of succession." *J. Exp. Mar. Biol. Ecol.*, Vol. 58, pp. 73-85.

Champ, M. A. and W. L. Pugh. 1987. "Tributyltin antifouling paints: introduction and overview." In, *Proceedings of the Ocean and International Workplace, Oceans '87, International Organotin Symposium*, Marine Technology Society, Washington, District of Columbia, Vol. 4, pp. 1296-1308.

Clavell, C., P. F. Seligman, and P. M. Stang. 1986. "Automated analysis of organotin compounds: a method for monitoring butyltins in the marine environment." In, *Proceedings of the Oceans '86 Conference, Organotin Symposium*, Marine Technology Society, Washington, District of Columbia, Vol. 4, pp. 1152-1154.

Coe, W. R., and W. E. Allen. 1937. "Growth of sedentary marine organisms on experimental blocks and plates for nine successive years, at the pier of the Scripps Institution of Oceanography." *Bull. Scripps Inst. Oceanogr.* Technical Series No. 4, pp. 101-136.

Davidson, B. M., A. O. Valkirs, and P. F. Seligman. 1986. "Acute and chronic effects of tributyltin on the mysid *Acanthomysis sculpta* (Crustacea, Mysidacea)." In, *Proceedings of the Oceans '86 Conference, Organotin Symposium*, Marine Technology Society, Washington, District of Columbia, Vol. 4, pp. 1219-1225.

Dean, T. A. 1981. "Structural aspects of sessile invertebrates as organizing forces in an estuarine fouling community." *J. Exp. Mar. Biol. Ecol.*, Vol. 53, pp. 163-180.

Dean, T. A., and L. E. Hurd. 1980. "Development in an estuarine fouling community: the influence of early colonists on later arrivals." *Oecol.*, Vol. 46, pp. 295-301.

Dodge, E. E., and T. C. Theis. 1979. "Effects of chemical speciation on the uptake of copper by *Chironomus tentuns*." *Envir. Sci. Technol.*, Vol. 13, pp. 1287-1293.

Donaghay, P. L. 1984. "Utility of mesocosms to assess marine pollution." In, *Concepts in Marine Pollution Measurements*, edited by H. H. White, Maryland Sea Grant, University of Maryland, College Park, Maryland, pp. 589-620.

Dygert, P. H. 1978. *The patterns of community metabolism in the development of a marine fouling community*. Master's Thesis, San Diego State University, San Diego, California, 75 pp.

Epifanio, C. E. 1984. "Effects of toxic substances on decapod larvae." In, *Concepts in Marine Pollution Measurements*, edited by H. H. White, Maryland Sea Grant, University of Maryland, College Park, Maryland, pp. 499-510.

Gadbois, L. E. 1984. *The response of benthic respiration to nutrient levels*. Master's Thesis, Virginia Institute of Marine Science, Gloucester Point, Virginia, 94 pp.

Gadbois, L. E., and B. J. Neilson. 1984. "Natural variability of water quality in a temperate estuary." In, *Statistical Aspects in Water Quality Monitoring*, edited by A. H. El-Shaarawi and R. E. Kwiatkowski, Elsevier, New York, New York, pp. 158-171.

Gilbert, R. O. 1987. *Statistical methods for environmental pollution monitoring*. Van Nostrand Reinhold Company, New York, New York, 320 pp.

Goren, M. 1979. "Succession of benthic community on artificial substratum at Elat (Red Sea)." *J. Exp. Mar. Biol. Ecol.*, Vol. 38, pp. 19-40.

Grassle, J. P., and J. F. Grassle 1984. "The utility of studying the effects of pollutants on single species populations in benthos of mesocosms and coastal communities." In, *Concepts in Marine Pollution Measurements*, edited by H. H. White, Maryland Sea Grant, University of Maryland, College Park, Maryland, pp. 621-642.

Gray, J. S. 1981. *The ecology of marine sediments*. Cambridge University Press, Cambridge, United Kingdom, 185 pp.

Gross, M. G. 1972. *Oceanography: A view of the earth*. Prentice-Hall, Englewood Cliffs, New Jersey, 135 pp.

Grovhoug, J. G., P. F. Seligman, G. Vafa, and R. L. Fransham. 1986. "Baseline measurements of butyltin in U.S. harbors and estuaries." In, *Proceedings of the Oceans '86 Conference, Organotin Symposium*, Marine Technology Society, Washington, District of Columbia, Vol. 4, pp. 1283-1288.

Grovhoug, J. G., and P. F. Seligman. 1987. "Butyltin Concentrations in Selected U.S. Harbor Systems: A Baseline Assessment." Naval Ocean Systems Center, Technical Report No. 1155, San Diego, California, 192 pp.

Henderson, R. S. 1985. "Effects of Tributyltin Antifouling Paint Leachates on Pearl Harbor Organisms: Site-specific Flow Through Bioassay Test." Naval Ocean Systems Center, Technical Report No. 1079, San Diego, California, 25 pp.

Henderson, R. S. 1988. "Marine Microcosm Experiments on Effects of Copper- and Tributyltin-Based Antifouling Paint Leachates." Naval Ocean Systems Center, Technical Report No. 1060, San Diego, California, 52 pp.

Horiba Instrument Incorporated. 1978. *Operation and service instruction model U-7 water quality checker*. Horiba Instrument Incorporated, Manual No. 90606, 35 pp.

Hurlbert, S. H. 1971. "The nonconcept of species diversity: a critique and alternative parameters." *Ecol.* Vol. 52, No. 4, pp. 577-586.

Hurlbert, S. H. 1981. "A gentle depilation of the niche: dicean resource sets in resource hyperspace." *Evol. Theory*, Vol. 5, pp. 177-184.

Hurlbert, S. H. 1984. "Pseudoreplication and the design of ecological field experiments." *Ecol. Monogr.*, Vol. 54, pp. 187-211.

Hutchinson, T. C. 1979. "Copper contamination of ecosystems caused by smelter activities." In, *Copper in the Environment, Part I, Ecological Cycling*, edited by J. O. Nruagu, Wiley, New York, New York, pp. 451-462.

Johnston, R. K., S. H. Lieberman, D. R. Bower, S. I. Inman, and P. Havens. 1986. "Copper survey of Kings Bay and Cumberland Sound, GA." In, *Proceedings of Marine Data Symposium 1986*, Marine Technology Society, Washington, District of Columbia, pp. 480-489.

Johnston, R. K., and D. Lapota. 1989. "A new approach for evaluating biological toxicity at aquatic hazardous waste sites." In, *Proceedings of the Coastal Zone '89*, Marine Technology Society, Washington, District of Columbia, in press.

Kenis, P., A. Zirino, and C. Clavell. 1977. "Automated Anodic Stripping Voltammetry for the Analysis of Copper, Zinc, Lead, and Cadmium for Environmental Monitoring." Naval Ocean Systems Center Technical Report No. 243, San Diego, California, 19 pp.

Lambshead, P. J. D., H. M. Platt, and K. M. Shaw. 1983. "The detection of differences among assemblages of marine benthic species based on an assessment of dominance and diversity." *J. Nat. Hist.*, Vol. 17, pp. 859-874.

Lane, S. M. K. 1980. "Productivity and Diversity of Phytoplankton in Relation to Copper Levels in San Diego Bay." Naval Ocean Systems Center, Technical Report No. 533, San Diego, California, 73 pp.

Lapota, D., and J. R. Losee. 1984. "Observations of bioluminescence in marine plankton from the Sea of Cortez." *J. Exp. Mar. Biol. Ecol.*, Vol. 77, pp. 209-214.

Lapota, D., C. Gault, J. R. Losee, H. D. Huddell, J. K. Orzech, and K. H. Nealson. 1988. "Observations and measurements of planktonic bioluminescence in and around a milky sea." *J. Exp. Mar. Biol. Ecol.*, Vol. 119, pp. 55-81.

Laughlin, R. B. , W. J. French, and H. E. Guard. 1983. "Acute and sublethal toxicity to tributyltin oxide (TBTO) and putative environmental product, tributyltin sulfide (TBTS) to zoel mud crabs, *Rhithropanopeus harrisii*." *Water Air Soil Pollut.*, Vol. 209, pp. 69-79.

Lee, R. F. 1986. "Metabolism of BIS(tributyltin) oxide by estuarine animals." In, *Proceedings of the Oceans '86 Conference, Organotin Symposium*, Marine Technology Society, Washington, District of Columbia, Vol. 4, pp. 1182-1188.

Levin, L. A. 1984. "Life history and dispersal patterns in a dense infaunal polychaete assemblage, community structure and response to disturbance." *Ecol.*, Vol. 65, No. 4, pp. 1185-1200.

Lieberman, S. H., V. Homer, and P. F. Seligman. 1984. "In Situ Determination of Butyltin Release Rates from Antifouling Coatings on Navy Test Ships." Naval Ocean Systems Center, Technical Report No. 1027, San Diego, California, 36 pp.

Lieberman, S. H., R. K. Johnston, D. R. Bower, and S. M. Inman. 1985. "A Survey of Copper in Kings Bay and Cumberland Sound." Naval Ocean Systems Center, Technical Report No. 1062, San Diego, California, 103 pp.

Long, E. R., and P. M. Chapman. 1985. "A sediment quality triad: measures of sediment contamination, toxicity and infaunal community composition in the Puget Sound." *Mar. Poll. Bull.*, Vol. 16, No. 10, pp. 405-415.

Lussier, S. M., J. H. Gentile, and J. Walker. 1985. "Acute and chronic effects of heavy metals and cynide on *Mysidopsis bahia* (Crustacea: Mysidacea)." *Aquatic Tox.*, Vol. 7, pp. 23-35.

Marine Computer Systems, Incorporated. 1986. *Tide and current prediction package for all U.S. reference stations 1986 to 1999*. Marine Computer Systems, North Lauderdale, Florida, Version 2.0a, 17 pp.

Meador, J. P. 1986. "An analysis of photobehavior of *Daphnia magna* exposed to tributyltin." In, *Proceedings of the Oceans '86 Conference, Organotin Symposium*, Marine Technology Society, Washington, District of Columbia, Vol. 4, pp. 1213-1218.

Niederlehner, B. R., J. R. Pratt, A. L. Buikema, Jr., and J. Cairns, Jr. 1986. "Comparison of estimates of hazard derived at three levels of complexity." In, *Community Toxicity Testing*, edited by J. Cairns, Jr., American Society for Testing and Materials, Philadelphia, Pennsylvania, No. 920, pp. 30-48.

NH Analytical Software. 1986. *STATISTIX: an interactive statistical analysis program for microcomputers*. NH Analytical Software, Roseville, Minnesota, 115 pp.

Osman, R. W. 1977. "The establishment and development of a marine epifaunal community." *Ecol. Mon.*, Vol. 47, pp. 37-63.

Osman, R. W. 1982. "Artificial substrates as ecological islands." In, *Artificial Substrates*, edited by J. Cairns, Jr., Ann Arbor Science, Ann Arbor, Michigan, pp. 23-37.

Paul, J. D., and I. M. Davies. 1986. "Effects of copper- and tin-based antifouling compounds on the growth of scallops (*Pecten macimus*) and oysters (*Crassostrea gigas*)." *Aquac.*, Vol. 54, pp. 191-203.

Peeling, T. P. 1975. "A Proximate Survey of San Diego Bay, California." Naval Undersea Technical Report No. 389, San Diego, California, Rev. 1, 86 pp.

Petersen, R. 1982. "Influence of copper and zinc on the growth of a freshwater algae, *Scenedesmus quadricauda*: the significance of speciation. *Envir. Sci. Tech.*, Vol. 16, pp. 443-449.

Reish, D. J. 1972. *Marine life of Southern California, emphasizing marine life of Los Angeles and Orange Counties*. Donald J. Reish, Los Alamitos, California, 164 pp.

Ricketts, E. F., J. Calvin, J. W. Hedgpeth, and D. W. Phillips. 1985. *Between pacific tides*. Stanford University Press, Stanford, California, fifth edition, 451 pp.

Salazar, M. H. 1986. "Environmental significance and interpretation of organotin bioassays." In, *Proceedings of the Oceans '86 Conference, Organotin Symposium*, Marine Technology Society, Washington, District of Columbia, Vol. 4, pp. 1240-1245.

Salazar, M. H., and S. M. Salazar. 1985. "Ecological Evaluation of Organotin-Contaminated Sediment." Naval Ocean Systems Center, San Diego, California, Technical Report No. 1050, 21 pp.

Salazar, M. H., and S. M. Salazar. 1987. "Tributyltin effects on juvenile mussel growth." In, *Proceedings of the Ocean, an International Workplace, Oceans '87, International Organotin Symposium*, Marine Technology Society, Washington, District of Columbia, Vol. 4, pp. 1504-1510.

Salazar, S. M., B. M. Davidson, P. M. Stang, and K. Meyers-Schulte. 1987a. "Effects of TBT on marine organisms: field assessment of a new site-specific bioassay system." In, *Proceedings of the Ocean, an International Workplace, Oceans '87, International Organotin Symposium*, Marine Technology Society, Washington, District of Columbia, Vol. 4, pp. 1461-1470.

Salazar, S. M., M. H. Salazar, B. M. Davidson, P. M. Stang, and K. Meyers-Schulte. 1987b. "A Portable Environmental Test System: a Field Assessment of Organotin Leachates, Test and Evaluation." Naval Ocean Systems Center, Technical Report No. 1202, San Diego, California, 37 pp.

San Diego Unified Port District. 1972. *Natural physical factors of San Diego tidelands*. San Diego Unified Port District, Planning Department, San Diego, California, 47 pp.

Schoener, A. 1982. "Artificial substrates in marine environments." In, *Artificial Substrates*, edited by J. Cairns, Jr., Ann Arbor Science, Ann Arbor, Michigan, pp. 57-64.

Seligman, P. F., J. G. Grovhoug, and K. E. Richter. 1986a. "Measurement of butyltins in San Diego Bay, CA, A monitoring strategy." In, *Proceedings of the Oceans '86 Conference, Organotin Symposium*, Marine Technology Society, Washington, District of Columbia, Vol. 4, pp. 1289-1296.

Seligman, P. F., A. O. Valkirs, and R. F. Lee. 1986b. "Degradation of tributyltin in marine and estuarine waters." In, *Proceedings of the Oceans '86 Conference, Organotin Symposium*, Marine Technology Society, Washington, District of Columbia, Vol. 4, pp. 1189-1195.

Seligman, P. F., J. G. Grovhoug, A. O. Valkirs, P. M. Stang, R. Fransham, M. O. Stallard, B. Davidson, and R. F. Lee. 1989. "Distribution and fate of tributyltin in the United States marine environment." *Appl. Organom. Chem.*, Vol. 3, pp. 31-47.

Slobodkin, L. B. 1961. *Growth and regulation of animal populations*. Holt, Rinehart and Winston, New York, New York, 184 pp.

Slobodkin, L. B., and H. L. Sanders. 1969. "On the contribution of environmental predictability to species diversity." In, *Diversity and Stability in Ecological Systems, Brookhaven Symposium in Biology*. Brookhaven National Laboratory, Upton, New York, No. 22, pp. 82-95.

Smith, E. L. 1972. "Temperature Fluctuations at a Fixed Point in San Diego Bay, California." Naval Undersea Technical Report No. 298, San Diego, California, 36 pp.

Smith, R. I., and J. T. Carlton. 1975. *Light's manual: intertidal invertebrates of the central California coast*. University of California Press, Berkeley, California, third edition, 717 pp.

Smith, R. O. 1985. *Development of marine fouling communities near the SDG&E Encina Power Plant in Carlsbad, California*. San Diego State University Master's Thesis, San Diego, California, 196 pp.

Snedecor, G. W., and W. G. Cochran. 1980. *Statistical Methods*. Iowa State University Press, Ames, Iowa, seventh edition, 507 pp.

Sokal, R. R., and F. J. Rohlf. 1981. *Biometry*. W. H. Freeman & Company, San Francisco, California, second edition, 859 pp.

Stang, P. M. 1985. *Butyltin compounds in the sediment of San Diego Bay, California*. San Diego State University Master's Thesis, San Diego, California, 61 pp.

Stang, P. M., and P. F. Seligman. 1986. "Distribution and fate of butyltin compounds in the sediment of San Diego Bay." In, *Proceedings of the Oceans '86 Conference, Organotin Symposium*, Marine Technology Society, Washington, District of Columbia, Vol. 4, pp. 1256-1261.

Stallard, M. O., S. Y. Cola, and C. A. Dooley. 1989. "Optimization of butyltin measurements for seawater, tissue, and marine sediment samples." *Appl. Organomet. Chem.*, Vol. 3, pp. 105-114.

Stewart-Oaten, A., W. W. Murdoch, and K. R. Parker. 1986. "Environmental impact assessment: 'pseudo-replication' in time?" *Ecol.*, Vol. 67, No. 4, pp.929-940.

Sunda, W. G., and R. R. L. Guillard. 1976. "The relationship between cupric ion activity and the toxicity to phytoplankton." *J. Mar. Res.*, Vol. 34, pp. 511-529.

Sutherland, J. P., and R. H. Karlson. 1977. "Development and stability of the fouling community at Beaufort, North Carolina." *Ecol. Monogr.*, Vol. 47, pp. 425-446.

Tagatz, M. E., G. R. Plaia, and C. H. Deans. 1986. "Toxicity of dibutyl phythalate-contaminated sediment to laboratory- and field-colonized estuarine benthic communities." *Bull. Env. Contam. Toxicol.*, Vol. 37, pp. 141-150.

Taub, F. B., A. C. Kindiy, and L. C. Conquest. 1986. "Preliminary results of interlaboratory testing of a standardized aquatic microcosm." In, *Community Toxicity Testing*, edited by J. Cairn, Jr., American Society for Testing & Materials, Philadelphia, Pennsylvania, No. 920, pp. 93-120.

Thain, J. E. 1986. "Toxicity of TBT to Bivalves: Effects on Reproduction, Growth, and Survival." In *Proceedings of the Oceans '86 Conference, Organotin Symposium*, Marine Technology Society, Washington, D.C., Vol. 4, pp. 1256-1261.

Theiry, R. G. 1982. "Environmental instability and community diversity." *Biol. Rev.*, Vol. 57, pp. 671-710.

United States Army Corps of Engineers. 1975. *San Diego Harbor, San Diego County, California, final environmental impact statement*. Army Engineer District, Los Angeles, California, 212 pp.

United States Environmental Protection Agency. 1968. *Water quality criteria*. Environmental Protection Agency. Washington, District of Columbia, 108 pp.

United States Environmental Protection Agency. 1985. *Ambient water quality criteria for copper—1984*. Office of Water Regulations and Standards, Criteria and Standards Division. Washington, District of Columbia, No. 440/5-84-031, 142 pp.

U'ren, S. C. 1983. "Acute toxicity of bis (tributyltin) oxide to a marine copepod." *Mar. Poll. Bull.*, Vol. 14, pp. 303-306.

Valkirs, A. O., B. M. Davidson, and P. F. Seligman. 1985a. "Sublethal Growth Effects and Mortality to Marine Bivalves and Fish from Long-term Exposure to Tributyltin." Naval Ocean Systems Center, San Diego, California, Technical Report No. 1042, 65 pp.

Valkirs, A. O., P. F. Seligman, G. Vafa, P. M. Stang, V. Homer, and S. H. Lieberman. 1985b. "Speciation of Butyltins and Methyltin in Seawater and Marine Sediments by Hydride

Derivatization and Atomic Absorption Detection." Naval Ocean Systems Center, San Diego, California, Technical Report No. 1037, 41 pp.

Valkirs, A. O., P. F. Seligman, P. M. Stang, V. Homer, S. H. Lieberman, G. Vafa, and C. A. Dooley. 1986. "Measurement of butyltin compounds in San Diego Bay." *Mar. Poll. Bull.*, Vol. 17, No. 7, pp. 319-324.

Walsh, G. E., L. L. McLaughlan, E. M. Lores, M. K. Louie, and C. H. Deans. 1985. "Effects of organotins on growth and survival of two marine diatoms *Skeletonema costatun* and *Thalassiosira pseudonana*." *Chemosp.*, Vol. 14, pp. 383-392.

Washington, H. G. 1984. "Diversity, biotic, and similarity indices: a review with special relevance to aquatic ecosystems." *Water Res.*, Vol. 18, No. 6, pp. 653-694.

Warwick, R. M. 1986. "A new method for detecting pollution effects on marine macro-benthic communities." *Mar. Biol.*, Vol. 92, pp. 557-562.

White, H. H., and M. A. Champ. 1983. "The great bioassay hoax and alternatives." In, *Hazardous and Industrial Solid Waste Testing: Second Symposium*, edited by R. A. Conway and W. P. Gulledge, American Society for Testing and Methods, Philadelphia, Pennsylvania, Special Technical Publication No. 805, pp. 23-35.

Whittaker, R. H. 1965. "Dominance and diversity in land plant communities." *Sci.*, Vol. 147, pp. 250-260.

Whittaker, R. H. 1969. "Evolution of diversity in plant communities." In, *Diversity and Stability in Ecological Systems, Brookhaven Symposium in Biology*. Brookhaven National Laboratory, Upton, New York, No. 22, pp. 178-197.

Williams, K. A., D. W. J. Green, D. Pascoe, and D. E. Gower. 1986. "The acute toxicity of cadmium to different larval stages of *Chironomus riparius* (Diptera: Chironomidae) and its ecological significance for pollution regulation." *Oecol.*, Vol. 70, pp. 362-366.

Young, D. R., G. V. Alexander, and D. J. McDermott-Ehrlich. 1979. "Vessel-related contamination of Southern California harbours by copper and other metals." *Mar. Poll. Bull.*, Vol. 10, pp. 50-56.

Zirino, A., and S. H. Lieberman. 1975. "Automated anodic stripping voltammetry for the measurement of copper, zinc, cadmium and lead in seawater." In, *Analytical Methods in Oceanography*, edited by T. R. P. Gibbs, American Chemical Society, Washington, District of Columbia, pp. 47-63.

Zirino, A., S. H. Lieberman, and C. Clavell. 1978. "Measurement of Cu and Zn in San Diego Bay." *Envir. Sci. Tech.*, Vol. 12, pp. 73-79.

Zirino, A. 1981. "Voltammetry of natural seawater." In, *Marine Electro-Chemistry*, edited by M. Whitfield & D. Jagner, John Wiley & Sons, New York, New York, pp. 23-41.

Zirino, A., and P. F. Seligman. 1981. "Polarographic behavior of the Cu ion selective electrode." *Mar. Chem.*, Vol. 10, pp. 249-255.

Zirino, A., and R. K. Johnston. 1984. "Marine Environmental Quality Assessment Program Five Year Plan." Naval Ocean Systems Center, San Diego, California, Technical Document No. 761, 71 pp.

APPENDIX A

SPECIES LIST

This appendix contains an annotated list of organisms collected on panels, pilings, and docks of the Shelter Island Yacht Basin, San Diego, and the Naval Amphibious Base, Coronado, California. The species identified and the biomass measurements (g/50 cm^2) recorded from quantitative samples are listed (table 15).

Many of the species were sampled on the panels as juvenile or as small adults making exact identification difficult. Most genera and species were compared to adult specimens collected from the respective stations. Collections were made at the Naval Ocean Systems Center, Pier 159 (NOSC), the Shelter Island Harbor Police Boat Dock (HPBD), Southwestern Yacht Club, slip 63 (SWYC), the end of the Silvergate Yacht Club pier (SILVER), and the Naval Amphibious Base small boat dock (DOCK) (See figure 1). Collections were made on July 8, July 17, July 29, August 23, 1986, and January 23, 1987.

Kingdom Plantae
Phylum Rhodophyta
Family Ceramiaceae

Filamentous red algae were sampled on NOSC and DOCK panels. They were identified by their delicate filimentous structure and reddish pigmentation (Reish, 1972, pp. 146).

Phylum Phaeophyta

Scytosiphon lomentaria

Light brown algae consisting of branchless tube with periodic constrictions growing in an entangling mass. This species was sampled on only one panel at the NOSC station and one replicate established community sample at the HPBD station. *S. lomentaria* were a major component of the DOCK community (Reish, 1972, pp. 137).

Kingdom Animalia
Phylum Porifiera

Halichondria panicea

The "crumb-of-bread sponge." This sponge's surface consisted of regular reticulations of multispicular tracts and closely spaced pores. It was typically encrusting and was yellow, yellow-tan to olive green in color. This species was present in the established communities at the NOSC and SWYC stations and on panels at the HPDB and SWYC stations (Smith and Carlton, 1975, pp. 44, Plate 4; Allen, 1976, pp. 63).

Halicolna sp.

The "purple sponge." The sponge was lavender to purple in color with finger-like projections. It had small (<100 μm) oxeote spicules forming square to polygon meshes. This species was a component of the established community sampled at the HPBD, SWYC, and SILVER stations (Smith and Carlton, 1975, pp. 45, Plate 4; Allen, 1976, pp. 63, Plate 5).

Hymemiacidon sp.

An orange sponge with stylote spicules encrusting with pointed processes arising from its base. This species was present at the SWYC and HPBD stations (Smith and Carlton, 1975, pp. 46).

Leucosolenia sp.

A whitish sponge with oxeote and triradiate spicules with one ray longer than the others (sagittal) and rough finger-like vertical tubules. This sponge was commonly found in the NOSC, HPBD, SWYC, SILVER, and DOCK station samples (Smith and Carlton, 1975, pp. 46, Plate 5; Allen, 1976, pp. 61, Plate 5; Ricketts et al., 1985, pp. 122).

Phylum Cnidaria
Class Anthozoa

Diadume leucolena

A small olive green sea anemone with orangish vertical stripes and pale salmon tentacles. This organism was sampled on panels at the DOCK station (Reish, 1972, pp. 27; Smith and Carlton, 1975, pp. 89).

Class Hydrozoa

Obelia sp.

A colonial hydroid identified by the presence of a sleeve (hydrotheca) forming a protective cap around its mouth and tentacle bulb. It was rarely present. When it was found it was along the edge of the panels (Smith and Carlton, 1975, pp. 67; Reish, 1972, pp. 23).

Tubularia sp. (*Tubularia crocea*)

The naked hydroid, which lacks the sleeve. It was rarely found (Reish, 1972, pp. 23-4).

Unidentified

A branching stalked hydrozoan was found on a few of the panels at the NOSC station.

Phylum Annelida
Class Polychaeta
Order Sedentaria
Family Serpulidae

Spirorbis sp.
Spirorbis cf. *spirillum*
Spirorbis moerchi
Spirorbis borealis

A tube dwelling filter feeder with a tightly coiled smooth, dextral tube. The taxonomy of Spirorbinae is not well worked out so it was very difficult to identify this organism to species level. *Spirorbis* sp. was relatively abundant with individuals being sampled on virtually all panels. In late summer it was especially abundant growing in close association with *Hydroides pacificus*, such that the two species could not be separated (Reish, 1972, pp. 38-39; Smith and Carlton, 1975, pp. 241, Plate 53).

Hydroides pacificus

The most dominant species sampled during the study. It is a long (5-8 cm), fast growing, calcareous tube worm with a distinctive operculum. Heavy recruitment of *H. pacificus* occured on all the panels in Shelter Island during August 1986 (Reish, 1972, pp. 38-9).

Order Errantia
Family Nereidae

A number of errant polychaetes were sampled during the study. Most notable were *Nereis* sp., which were greenish with four eyes and a pharynx with a pair of jaws. Biomass determinations of

errant polychaetes were obtained from samples at the SWYC and SILVER stations (Reish, 1972, pp. 31; Smith and Carlton, 1975, pp. 190, Plate 35; Barnes, 1980, pp. 527).

Phylum Mollusca
Class Gastropoda

Unidentified gastropod larvae and egg masses were sampled on a number of DOCK panels.

Order Archaeogastropoda
Family Acmaeidae (Limpets)

Acmaea spp.

Small limpets, possibly juvenile *A. limatula* or *A. pelta* were present on a couple of the panels sampled from the NOSC station. Larger limpets (*A. digitalis*) were a component of the established community at the NOSC station and were observed at other Shelter Island stations (Reish, 1972, pp. 42- 43).

Subclass Opisthobranchia
Order Anaspidea
Family Aplysiidae

Aplysia californica

The "sea hare." Small specimens, reddish with light colored bands on the upper inner surfaces, were observed at stations in Shelter Island and at the DOCK station (Reish, 1972, pp. 55; Smith and Carlton, 1975, pp. 521; Morris et al., 1980, pp. 313, Plate 97).

Order Nudibranchia

A variety of nudibranchs were encountered during the study. Nudibranchs were quantified on panels from the NOSC station but were not identified to species level.

Class Pelecypoda(=Bivalvia)
Order Mytiloida
Family Mytilida

Mytilus sp.
Mytilus edulis
Mytilus californianus

The common bay mussel or blue mussel. Juvenile *Mytilus* were sampled on only a few of the panels from the DOCK station at the end of the study. *Mytilus* was also sampled as part of the established community at the NOSC station, while both *M. edulis* and *M. californianus* were observed growing on pilings and floats at the NOSC station (Reish, 1972, pp. 59; Smith and Carlton, 1975, pp. 552, Plate 125; Morris et al., 1980, pp. 300-302, Plate 125).

Order Pterioida
Family Ostreidae

Ostrea lurida

The native oyster was observed growing at depth on pilings within Shelter Island but was not quantified during the study (Reish, 1972, pp. 61; Smith and Carlton, 1975, pp. 556; Allen, 1976, pp. 168; Morris et al., 1980, pp. 364).

Phylum Arthropoda
Class Crustacea
Subclass Cirripedia
Order Thoracea

Balanus spp.
Balanus amphitrite—fine pink to purple lines.
Balanus glandula—pacific acorn barnacle with white to olive ribbed walls.
Balanus tintinnabulum californicus—red and white barnacle with fine white lines and radii permeated by transverse tubes. Members of this genus were a major component of the established community at the NOSC station and were also observed at other stations within Shelter Island (Reish, 1972, pp. 73-74; Smith and Carlton, 1975 pp. 262- 267; Allen, 1976, pp. 209-212, Plate 25).

Chthamalus fissus
Small gray-brown acorn barnacle was observed at stations in Shelter Island but was not present in any of the quantitative samples. (Reish, 1972, pp. 73-74; Smith and Carlton, 1975, pp. 262-267; Allen, 1976, pp. 209-212, Plate 25).

Division Peracarida
Order Tanaidacea

A few individuals of this order (probably from the genus *Tanais*) were identified by the presence of gnathopods (first pair of legs) bearing pincers (chelae) with the first two thoracic somites fused to the animal's head. Individuals from this group were counted with isopods (Smith and Carlton, 1975, pp. 271-276).

Order Isopod

A few to many isopods were captured on panels and in grabs of established communities. Individuals encountered were usually from the Families Idoteia (genus *Idotea*) or Spaeromatid (*Paracerceis* sp.) (Smith and Carlton, 1975, pp. 281-309, Plate 63; Allen, 1976, pp. 217, Plates 27 and 28).

Order Amphipoda
Suborder Gammaridea

Ericthonius sp. (*E. brasiliensis*)
A tube building gammarid amphipod. Empty tubes consisting of detritus were included in measurements of this species' biomass. An assortment of unidentified gammarid amphipods were also sampled. (Smith and Carlton, 1975, pp. 332-334, Plates 76 and 80).

Suborder Caprellidea

A few skeleton shrimp (genus *Caprella*) were collected from panels. These were primarily found in tangled mats of *Scytosiphon lomentaria* on panels from the DOCK station (Reish, 1972, pp. 80; Smith and Carlton, 1975, pp. 367-375, Plates 89 and 90).

Subclass Eucarida
Order Decapoda

Pinnixa sp. (*P. franciscana*)
A very small (about 10 mm) tannish pea crab. It was collected on panels from the DOCK station and in grab samples from the NOSC and HPBD stations (Reish, 1972, pp. 88; Smith and Carlton, 1975, pp. 396-398; Allen, 1976, pp. 256, Plate 36; Morris et al., 1980, pp. 616-618, Plates 184 and 185).

Lophopanopeus sp.

A small (less than 25 mm) crab with black pincers and sharp teeth on the lateral margin of its carapice. It was collected primarily in samples from the DOCK station (Reish, 1972, pp. 87; Smith and Carlton, 1975, pp. 398-399, Plate 97; Allen, 1976, pp. 254, Plate 35; Morris et al., 1980, pp. 609-610, Plates 181 and 182).

Phylum Ectoprocta (=Bryozoa)
Order Cheilostomata

Bugula sp.
Bugula californica
Bugula neritina

The "seaweed moss animal." An erect branching cheilostomat with reticulate zoea. *B. californica* is identified by its spiral whorls of branches and distinctive avicularia. *B. neritina* is red to purple and lacks avicularia. *Bugula* spp. were dominant on panels at the NOSC station and present on almost all panels sampled (Reish, 1972, pp. 89; Smith and Carlton, 1975, pp. 597, Plate 140; Allen, 1976, pp. 260; Morris et al., 1980, pp. 95-96, Plate 33).

Cryptosula pallasiana

The "pitted moss animal." This grayish, orange encrusting cheilostomat has irregular, spineless, finger-like zoea with numerous distinctive pits. It was identified at the HPBD and DOCK stations (Reish, 1972, pp. 91-92; Smith and Carlton, 1975; Allen, 1976, pp. 261-263, Plate 37).

Watersipora cf. *arcuata*
(*Hippodiplosia americana*)
Hippodiplosia insculpta

Encrusting cheilostomat with fan-like sheets of zooids light yellow to tan (*H. insculpta*) to bright reddish orange (*H. americana*) with a black dot on the individual zooids. However, the bryozoan may actually be *Watersipora* cf. *arcuata* (E. Corets, San Diego State University, personal communication) because the specimens examined lacked ovicells and have the distinctive aperture described by Banta (1969). These species were commonly found on almost all of the panels (Smith and Carlton, 1975, pp. 599, Plate 142; Morris et al., 1980, pp. 97-8, Plates 34-5; Ricketts et al., 1985, pp. 184-186).

Holoporella brunnea

A dark gray encrusting cheilostomat with a random arrangement of individual zooids. It was sampled on many of the Shelter Island panels. (Reish, 1972, pp. 91).

Membranipora sp.

The "jack frost" or "gulfweed moss animal." A white encrusting colony having a single flat layer of thin reticulate zoea arranged in a radiating honey comb lattice. Many fairly large sheets of *Membranipora* were identified on the panels from the NOSC and DOCK stations (Reish, 1972, pp. 92; Allen, 1976, pp. 259-260, Plate 37; Morris et al., 1980, pp. 94, Plate 32).

Schizoporella unicornis

A white to light orange encrusting colony consisting of hexagonal zoea with U-shaped proximal cavities (sinus). *S. unicornis* was present on many of the panels sampled from the NOSC and DOCK stations and a few of the panels from the HPBD and SWYC stations (Reish, 1972, pp. 91; Smith and Carlton, 1975, pp. 97, Plate 34; Morris et al., 1980, pp. 97, Plate 34).

Thalamoporella sp.

The "chambered moss animal." A branching colony consisting of pinkish zoea arranged in a uniform linear series with numerous distinct pits and small blunt spines divided into forked nodes or

joints. This species was only found on panels from the NOSC station (Allen, 1976, pp. 260, Plate 37; Morris et al., 1980, pp. 94-95, Plate 32).

Order Ctenostomata

Zoobotryon verticillatum

A white stringy vine-like branching ectoproct with barrel-like, ovoid gelatinous zoea forming twisting spaghetti-like chains. *Z. verticillatum* was sampled at the NOSC and HPBD stations (Reish, 1972, pp. 9; Morris et al., 1980, pp. 101, Plate 37).

Order Cyclostomata

Disporella sp.

An encrusting ectoproct whose colonies are shaped like irregular discs with tubules in radiate rows (Smith and Carlton, 1975, pp. 586-587).

Crisulipora occidentalis

A white branching ectoproct with individual zoea sticking out from the colony's stem (Reish, 1975, pp. 90).

Phylum Chordata
Subphylum Urochordata
Class Ascidiacea
Order Aplousobranchia

Aplidium californicum

Colonies of this encrusting tunicate were present on many panels in Shelter Island. The colonies were identified by their yellowish transparent tunic and orangish brown zoea arranged in distinctive clusters (Morris et al., 1980, pp. 182, Plate 57).

Amoroucium californicum

The "sea pork" tunicate. Colonies look like chunks of salt pork. This species was sampled in grab samples taken from the HPBD and SILVER silver stations (Reish, 1972, pp. 101).

Diplosoma spp.
Diplosoma pizoni
Diplosoma macdonaldi

A colonial tunicate which forms slimy sheets of transparent tunics with individual yellow-brown zoea scattered in the gelatinous matrix. *Diplosoma* spp. were tedious to sample because the slimy colonies would cover many other organisms, especially *Hydroides pacificus*. *Diplosoma* spp. were present on most of the panels sampled (Reish, 1972, pp. 102; Morris et al., 1980, pp. 188, Plate 60).

Order Phlebrobranchia

Ciona intestinalis

A solitary tunicate, sometimes joined in clumps, pale in color with a soft transparent tunic and yellowish pharynx, gut, gonoducts, and longitudinal muscles. *C. intestinalis* was collected on almost all panels and early juveniles looked like a fried egg (Reish, 1972, pp. 102; Morris et al., 1980, pp. 196-198).

Perophora annectens

A pale yellow colonial tunicate consisting of yellow-green globular zoea arranged to form dense plaques with easily distinguishable incurrent and excurrent siphons. *P. annectens* was sampled on only

a few of the panels at the DOCK station (Reish, 1972, pp. 102; Morris et al., 1980, pp. 198-199, Plate 64).

Polyclinum planum

A pale brown, round colonial tunicate with distinctive groups of zoea attached to a cylindrical penduncle (stalk). *P. planum* was sampled at the NOSC and SILVER stations (Allen, 1976, pp. 289-290, Plate 41; Morris et al., 1980, pp. 184, Plate 58).

Order Stolidobranchia

Botrylloides spp.

A colonial tunicate consisting of elongated chain-like rows of zoea, orange to whitish in color. *Botrylloides* spp. were sampled on panels from the NOSC, SILVER, and DOCK stations (Morris et al., 1980, pp. 204, Plate 64).

Botryllus spp.

A colonial tunicate arranged in daisy shaped clusters of individuals sharing a common central excurrent siphon. Specimens of *Botryllus* sampled on the panels included black as well as reddish individuals. *Botryllus* spp. was collected from many Shelter Island and DOCK samples. (Reish, 1972, pp. 101; Morris et al., 1980, pp. 203, Plate 64).

Pyura haustor

A solitary brownish tunicate with irregular shaped, very tough, leathery, tunic and distinctive reddish siphons. *P. haustor* were present in grab samples from the SWYC and SILVER stations and on panels collected from the NOSC and DOCK stations (Reish, 1972, pp. 103; Morris et al., 1980, pp. 210, Plate 66).

Styela spp.
Styela montereyensis
Styela plicata
Styela truncata

Solitary yellow to dark red, tough leathery tunicates found on many panels and a common component of the established communities. *S. montereyensis* has an elongated cylindrical shape, *S. truncata* is oval and squat, and *S. plicata* is ovid with lumpy wrinkles giving it the appearance of a brain. It was very difficult to tell juveniles of this genus apart. (Reish, 1972, pp. 103; Morris et al., 1980, pp. 206-210, Plate 65).

Unidentified

This species resembled a blackish material that gave the impression of a tunic. It was very difficult to identify individual zoea in the material. This species was only collected from panels exposed 9 weeks at the HPBD static

UNKNOWN

Unknown A

Samples of this specimen looked like small oval puffballs or pieces of styrofoam. They were attached to panels in small clumps.

BIBLIOGRAPHY

Allen, R. K. 1976. *Common intertidal invertebrates of Southern California*. Peek Publications, Palo Alto, California, 316pp.

Banta, W. C. 1969. "*Watersipora arcuata*, a new species in the *Subovoidea-Cucullatu-Nigra* complex (Bryozoa, Cheilostomata)." *Bull. So. Calif. Acad. Sci.*, Vol. 68, No. 2, pp. 96-102.

Barnes, R.D. 1980. *Invertebrate zoology*. Saunders College, Philadelphia, Pennsylvania, 632 pp.

Morris, R. H., D. P. Abbot, and E. C. Haderlie. 1980. *Intertidal invertebrates of California*. Stanford University Press, Stanford, California, 690 pp.

Reish, D.J. 1972. *Marine life of Southern California, emphasing marine life of Los Angeles and Orange Counties*. Donald J. Reish, Los Alamitos, California, 164 pp.

Ricketts, E. F., J. Calvin, J. W. Hedgpeth, and D.W. Phillips. 1985. *Between pacific tides*. Stanford University Press, Stanford, California, fifth edition, 451 pp.

Smith, R. I., and J. T. Carlton. 1975. *Light's manual: intertidal invertebrates of the central California coast*. University of California Press, Berkeley, California, third edition, 717 pp.

Table A-1. List of species and biomass (grams/50cm**2) sampled at each station location during the study. The samples were collected at Naval Ocean Systems Center Pier 159 (NOSC), Harbor Police Boat Dock (HPBD), Southwestern Yacht Club (SWYC), Silvergate Yacht Club (SWYC), and the Naval Amphibious Base small boat dock (DOCK). The samples were collected from panels exposed from June 17 to July 8 (0-21), July 8 to July 29 (21-42), July 29 to Aug 23 (42-63), and June 17 to August 23 (9-WK). Established communities were sampled on July 19, 1986 (Est1) and Jan 23, 1987 (Est2).

Taxon or species	NOSC					HPBD						SWYC					
	0-21	21-42	42-63	9-WK	Est2	0-21	21-42	42-63	9-WK	Est1	Est2	0-21	21-42	42-63	9-WK	Est1	Est2
Kingdom Plantae (Algae)																	
Phylum Rhodophyta																	
Family Ceramiaceae					0.084												
Phylum Phaeophyta																	
Scytosiphon lomentaria	0.054									0.008							
Kingdom Animalia																	
Phylum Porifera																	
Halichondria panicea					0.201				0.172		0.133					0.128	0.337
Haliclona sp.											0.078						0.729
Hymeniacidon sp.											0.005						1.526
Leucosolenia sp.					0.783				0.017	0.043	0.176						0.062
Phylum Cnidaria																	
Diadume leucolena																	
Class Hydrozoa					0.279												
Obelia sp.																	
Tubularia crocea																	
Unidentified				0.027													
Phylum Annelida																	
Class Polychaeta																	
Family Serpulidae			0.136	5.037					10.050	2.289			2.51	35.236	2.301	5.536	
Hydroides pacificus	0.020	0.002			0.017	0.442	0.034	1.433			6.091	1.114	0.039				
Spirorbis sp.	0.006	0.001			0.085	0.051	0.065	0.098				0.022	0.012				
Order Errantia																	
Family Nereidae (Nereis sp.)																	0.010

Table A-1 cont.

Taxon or species	NOSC					HPBD						SWYC					
	0-21	21-42	42-63	9-WK	Est2	0-21	21-42	42-63	9-WK	Est1	Est2	0-21	21-42	42-63	9-WK	Est1	Est2
Phylum Mollusca																	
Class Gastropoda																	
Family Acmaeidae (Acmaea spp.)					1.948												
Family Aplysiidae (Aplysia sp.)																	
Order Nudibranchia				0.006													
Class Pelecypoda(=Bivalvia)																	
Mytilus edulis					14.869												
Mytilus californianus																	
Ostrea lurida																	
Phylum Arthropoda																	
Order Thoracica																	
Balanus spp					26.160												0.141
Balanus amphitrite																	
Balanus glandula																	
Balanus tintinnabulum																	
Chthamalus fissus																	
Order Tanaidacea																	
Order Isopoda				0.014											0.011		0.011
Order Amphipoda					0.065	0.009	0.000				0.003						0.116
Family Gammaridea	0.002																
Ericthonius sp.			0.003	0.575					0.106			0.008		0.008	0.769		
Family Caprellidae(Caprella sp.)				0.009		0.011											
Order Decopoda					0.062												
Lophopanopeus sp.																	
Pinnixa sp.				0.001							0.003						
Phylum Ectoprocta(=Bryozoa)																	
Order Cheilostomata																	
Bugula spp.					0.151	0.003			0.424		0.492				0.279		0.116
Bugula californica	0.004											0.002					
Bugula neritina		0.003	0.006	7.268			0.001			0.013						0.018	
Cryptosula pallasiana										0.120							
Hippodiplosia americana	0.003		0.003	0.261	1.408	0.002	0.001	0.007	0.471	0.377	0.314		0.001		0.007	0.032	0.187
Hippodiplosia insculpta																	
Holoporella brunnea		0.008		0.363	2.638		0.002				0.001						

Table A-1 cont.

Taxon or species	NOSC					HPBD						SWYC					
	0-21	21-42	42-63	9-WK	Est2	0-21	21-42	42-63	9-WK	Est1	Est2	0-21	21-42	42-63	9-WK	Est1	Est2
Membranipora sp.	0.005			0.126													
Schizoporella unicornis	0.002	0.001		0.026					0.000	0.036						0.005	0.012
Thalamoporella sp.				0.022													
Order Ctenostomata																	
Zoobotryon verticillatum	0.000	0.002	0.010	0.031	0.686						0.081						
Order Cyclostomata																	
Crisulipora occidentalis																	
Disporella spp.																	
Phylum Chordata																	
Subphylum Urochordata(=Tunicata)																	
Class Ascidiacea																	
Amaroucium californicum										0.124							
Aplidium californicum		0.002									0.016						0.003
Botrylloides spp.				0.091													
Botryllus spp.		0.001	0.004	1.426					0.182		0.028	0.004		0.020	2.250		0.008
Ciona intestinalis	0.003		0.013	0.713				0.001	0.026		0.042		0.002	0.003	2.969	0.002	2.900
Diplosoma spp.	0.010	0.004	0.027	0.337		0.031		0.048	0.855		0.004	0.084	0.021	0.605	2.502	0.323	0.083
Diplosoma macdonaldi																	
Diplosoma pizoni																	
Perophora annectens																	
Polyclinum planum				0.005													
Pyura haustor	0.000															0.128	
Styela spp.						0.004											
Styela montereyensis					0.266												2.211
Styela plicata					0.246				0.025	0.065	1.145						0.249
Styela truncata																	
Unidentified									1.279								
UNKNOWN											0.057						

Table A-1 cont.

Taxon or species	SILVER						DOCK			
	0-21	21-42	42-63	9-WK	Est1	Est2	0-21	21-42	42-63	9-WK
Kingdom Plantae (Algae)										
Phylum Rhodophyta										
Family Ceramiaceae								0.002	0.000	0.120
Phylum Phaeophyta										
Scytosiphon lomentaria							3.345	0.433	0.140	2.466
Kingdom Animalia										
Phylum Porifera										
Halichondria panicea										
Haliclona sp.						0.932				
Hymeniacidon sp.										
Leucosolenia sp.					0.071	0.163				0.034
Phylum Cnidaria										
Diadume leucolena								0.004		
Class Hydrozoa										
Obelia sp.										
Tubularia crocea										
Unidentified										
Phylum Annelida										
Class Polychaeta							0.012			
Family Serpulidae				15.658	3.113	17.898				0.037
Hydroides pacificus	0.619	0.044	1.872							
Spirorbis sp.	0.091	0.123	0.037					0.000	0.002	
Order Errantia				0.031						
Family Nereidae (Nereis sp.)										

Table A-1 cont.

Taxon or species	SILVER						DOCK			
	0-21	21-42	42-63	9-WK	Est1	Est2	0-21	21-42	42-63	9-WK
Phylum Mollusca										
Class Gastropoda							0.007			
Family Acmaeidae (Acmaea spp.)										
Family Aplysiidae (Aplysia sp.)										
Order Nudibranchia										
Class Pelecypoda(=Bivalvia)										
Mytilus edulis										0.178
Mytilus californianus										
Ostrea lurida										
Phylum Arthropoda										
Order Thoracica										
Balanus spp										
Balanus amphitrite										
Balanus glandula										
Balanus tintinnabulum										
Chthamalus fissus										
Order Tanaidacea				0.004						
Order Isopoda							0.002	0.002	0.000	
Order Amphipoda						0.044	0.005		0.007	0.000
Family Gammaridea							0.038	0.043		
Ericthonius sp.				0.088						
Family Caprellidae(Caprella sp.)							0.047	0.036		
Order Decopoda										
Lophopanopeus sp.								0.008		0.263
Pinnixa sp.							0.032			
Phylum Ectoprocta(=Bryozoa)										
Order Cheilostomata										
Bugula spp.		0.001								
Bugula californica					0.004		0.006			
Bugula neritina				0.007			0.006			
Cryptosula pallasiana								0.022		
Hippodiplosia americana	0.001				0.086	0.177	0.009	0.000		0.016
Hippodiplosia insculpta										
Holoporella brunnea										0.150

Table A-1 cont.

Taxon or species	SILVER						DOCK			
	0-21	21-42	42-63	9-WK	Est1	Est2	0-21	21-42	42-63	9-WK
Membranipora sp.									0.018	0.871
Schizoporella unicornis							0.010	0.008	0.005	1.380
Thalamoporella sp.										
Order Ctenostomata										
Zoobotryon verticillatum										
Order Cyclostomata										
Crisulipora occidentalis										
Disporella spp.										
Phylum Chordata										
Subphylum Urochordata(=Tunicata)										
Class Ascidiacea										
Amaroucium californicum					0.061					
Aplidium californicum				0.070						
Botrylloides spp.				0.082				0.009		0.011
Botryllus spp.	0.008	0.001		0.354	0.007			0.004		
Ciona intestinalis	0.041		0.002	0.087		1.819		0.002	0.001	2.804
Diplosoma spp.	0.069	0.013	0.025	0.973	0.114	0.539	0.065		0.035	1.961
Diplosoma macdonaldi								0.032		
Diplosoma pizoni								0.021		
Perophora annectens									0.001	0.012
Polyclinum planum					0.000					
Pyura haustor					0.057					0.072
Styela spp.		0.001								0.006
Styela montereyensis						0.054				
Styela plicata					0.165		0.002	0.009		
Styela truncata										
Unidentified										
UNKNOWN										

APPENDIX B

PHYSICAL AND CHEMICAL DATA

day	date	time	tide	station	CuASV1	CuASV2	CuASV3	ASVave	CuICP1	CuICP2	CuICP3	ICPave	MBTL	DBTL	TBTL	temp	pH	DO	cond
day	date	time	tide	station	CuASV1	CuASV2	CuASV3	ASVave	CuICP1	CuICP2	CuICP3	ICPave	MBTL	DBTL	TBTL	temp	pH	DO	cond
0	6/17/86	713	H	NOSC	4.7800	3.8400		4.3100	6.7900	5.1500	7.5300	6.4900	0.0829	0.1007	0.1175				
0	6/17/86	1500	M	NOSC	2.7000			2.7000	5.6500	5.3100	5.0700	5.3433	0.0193	0.0170	0.0030				
0	6/17/86	1110	L	NOSC	4.8400	4.7400		4.7900	8.7200	8.8100	8.6300	8.7200	0.0488	0.1053	0.0550				
0	6/17/86	725	H	SWYC	9.1900	10.4400	11.4000	10.3433	15.0500	14.4100	14.1800	14.5467	0.0808	0.4056	0.3200				
0	6/17/86	1518	M	SWYC	9.4800	9.5300		9.5050	10.0100	10.1400	12.1400	10.7633	0.1610	0.3280	0.4050				
0	6/17/86	1050	L	SWYC	9.4600	11.4800	8.9900	9.9767	12.8200	12.9500	13.3400	13.0367	0.1100	0.4200	0.3550				
0	6/17/86	751	H	SILVER	14.7000	15.2700	13.1500	14.3733	15.0800	15.6700	14.9600	15.2367	0.0930	0.4050	0.3255				
0	6/17/86	1536	M	SILVER	12.8400	11.6400		12.2400	13.8000	12.4200	14.5400	13.5867	0.0870	0.4085	0.3215				
0	6/17/86	1145	L	SILVER	14.0900	10.8300	11.3300	12.0833	12.7500	13.0900	12.9100	12.9167	0.1155	0.3845	0.2860				
0	6/17/86	811	H	HPBD	10.5100	10.4400		10.4750	10.9500	9.6900	9.8300	10.1567	0.0941	0.3386	0.2020				
0	6/17/86	1551	M	HPBD	7.5600	8.8300	7.8900	8.0933	9.9400	9.7600	9.2800	9.6600	0.0745	0.2515	0.0575				
0	6/17/86	1230	L	HPBD	6.2400	8.2900	8.5700	7.7000	7.5700	8.1100	8.2100	7.9633	0.0915	0.2625	0.3010				
10	6/27/86	817	L	NOSC	4.6800	3.5100		4.0950	5.2100	4.8900	6.5300	5.5433	0.0230	0.0278	0.0513	20.00	7.20	7.90	52.30
10	6/27/86	835	L	SWYC	5.0800	5.6500		5.3650	9.4400	9.6200	9.7300	9.5967	0.0640	0.0970	0.1075	19.70	6.50	8.50	52.00
10	6/27/86	855	L	SILVER	8.5500	10.8700		9.7100	8.4700	10.3300	8.9800	9.2600	0.0804	0.2220	0.3768	20.00	6.00	8.10	52.70
10	6/27/86	911	L	HPBD	5.8800	6.3800		6.1300	5.7000	5.6200	6.4500	5.9233	0.0616	0.1572	0.1479	20.20	6.00	8.60	52.50
10	6/27/86	1133	M	NOSC	2.1900			2.1900	4.9300	5.4100	5.7100	5.3500	0.0203	0.0093	0.0165	19.10	6.10	8.40	51.40
10	6/27/86	1155	M	SWYC	5.3600	6.5800	10.0500	7.3300	9.0700	8.6400	10.2100	9.3067	0.0600	0.0810	0.0585	20.70	6.00	8.70	52.50
10	6/27/86	1215	M	SILVER	5.4600	4.6500		5.0550	10.3300	9.6900	9.6600	9.8933	0.0485	0.1091	0.0879	20.70	6.00	8.10	53.00
10	6/27/86	1230	M	HPBD	5.5900	5.7500		5.6700	6.1300	5.2900	5.3900	5.6033	0.0633	0.1658	0.5361	20.60	6.00	8.30	52.80
10	6/27/86	1540	H	NOSC	2.1900			2.1900	3.4500	3.3600	5.1700	3.9933	0.0248	0.0185	0.0633	19.30	6.00	8.20	51.30
10	6/27/86	1557	H	SWYC	4.2600	3.5900		3.9250	8.2000	9.4700	10.5200	9.3967	0.0532	0.0776	0.0952	20.30	6.00	8.70	52.70
10	6/27/86	1619	H	SILVER	7.1800	6.4700		6.8250	9.7900	9.5400	9.9300	9.7533	0.0632	0.1476	0.1752	21.40	6.00	9.60	53.60
10	6/27/86	1636	H	HPBD	5.9700	4.9600		5.4650	5.2400	4.7500	5.3900	5.1267	0.0406	0.0929	0.1232	21.00	6.00	9.40	53.30
21	7/8/86	553	L	NOSC	2.0200	2.0500		2.0350	7.5300	6.0300	5.0800	6.2133	0.0270	0.0593	0.0458	21.00	7.50	9.60	52.70
21	7/8/86	607	L	SWYC	9.1700	7.6200		8.3950	10.8200	10.5600	11.4100	10.9300	0.1170	0.2510	0.4300	21.20	7.30	9.30	53.10
21	7/8/86	627	L	SILVER	13.9500	8.3600	14.7200	12.3433	12.4700	12.3600	12.2300	12.3533	0.1840	0.3545	0.3680	21.50	7.30	9.60	53.60
21	7/8/86	642	L	HPBD	8.9300	5.5200	7.4500	7.3000	7.9900	7.7900	8.0500	7.9433	0.1275	0.2550	0.4575	21.20	7.30	9.40	53.20
21	7/8/86	957	H	NOSC	2.0200	2.0500		2.0350	7.1700	6.4000	5.0600	6.2100	0.0150	0.0268	0.0323	21.40	7.80	6.30	52.80
21	7/8/86	1024	H	SWYC	8.1100	8.6500	7.2700	8.0100	10.4400	10.3400	12.3500	11.0433	0.1400	0.1984	0.2788	21.60	7.80	6.40	53.30
21	7/8/86	1056	H	SILVER	10.7300	12.6600	12.2600	11.8833	11.0200	11.4100	11.5800	11.3367	0.1390	0.2575	0.4125	22.00	7.80	6.70	53.80
21	7/8/86	1120	H	HPBD	6.7400	5.0400	5.3200	5.7000	6.1900	5.8300	6.4800	6.1667	0.1109	0.2030	0.4123	21.90	7.90	6.90	53.50
21	7/8/86	1457	M	NOSC	2.4600	2.2700	2.5000	2.4100	5.0100	3.3100	3.2700	3.8633	0.0395	0.0543	0.0663	21.40	7.90	6.30	52.80

day	date	time	tide	station	CuASV1	CuASV2	CuASV3	ASVave	CuICP1	CuICP2	CuICP3	ICPave	MBTL	DBTL	TBTL	temp	pH	DO	cond
21	7/8/86	1511	H	SWYC	8.8900	7.5000	7.5900	7.9933	9.8200	10.2300	9.3700	9.8067	0.1340	0.2375	0.3215	22.50	8.00	6.30	54.40
21	7/8/86	1530	H	SILVER	8.4100	11.1700	8.6700	9.4167	9.1900	9.1700	10.0800	9.4800	0.1868	0.3096	0.3912	22.50	8.00	6.40	54.80
21	7/8/86	1544	H	HBPD	7.6600	7.8800		7.7700	6.7400	6.8400	6.6700	6.7500	0.0926	0.1435	0.1772	22.20	7.90	6.70	54.00
31	7/18/86	822	H	NOSC	2.4100	3.3100	3.6400	3.1200	5.9100	5.5500	3.2400	4.9000	0.0370	0.0680	0.2100	18.90	7.90	7.10	50.50
31	7/18/86	841	H	SWYC	21.6700	19.0200	20.5500	20.4133	13.2500	12.7500	12.8300	12.9433	0.1690	0.5820	0.9050	20.80	7.80	7.50	52.70
31	7/18/86	902	H	SILVER	14.6000	14.4200		14.5100	14.4400	14.8200	14.1100	14.4567	0.1160	0.7280	0.6300	21.90	7.80	6.70	53.80
31	7/18/86	918	H	HBPD	9.3400	8.4800	9.3500	9.0567	7.0700	8.6800	8.1400	7.9633	0.0930	0.3820	0.5260	20.60	7.70	6.90	52.40
31	7/18/86	1209	L	NOSC	3.4900	3.8200	3.1500	3.4867	3.9100	4.4100	4.7100	4.3433	0.0740	0.0980	0.1440	19.70	7.80	7.20	51.50
31	7/18/86	1224	L	SWYC	12.6500	15.1000	12.2000	13.3167	16.1600	16.1200	15.1700	15.8167	0.1580	0.5890	0.6070	21.30	7.80	6.70	52.80
31	7/18/86	1244	L	SILVER	11.8500	12.4800	11.8000	12.0433	13.6500	12.4600	11.0400	12.3833	0.1320	0.5300	0.7160	22.00	7.90	6.40	53.90
31	7/18/86	1259	L	HBPD	24.1800	18.0600	20.8200	21.0200	7.3300	7.2000	7.8100	7.4467	0.0950	0.2810	0.3750	21.50	7.90	7.10	53.60
31	7/18/86	1721	H	NOSC	1.4800	1.1600		1.3200	1.1500	1.1200	1.6200	1.2967	0.0100	0.0250	0.0370	17.90	7.90	7.90	49.80
31	7/18/86	1735	H	SWYC	16.9500	21.8600		19.4050	12.9700	13.6700	11.7100	12.7833	0.1480	0.4820	0.6880	21.90	7.90	7.10	54.40
31	7/18/86	1755	H	SILVER	11.5300	11.4900	12.8800	11.9667	14.1800	13.6400	12.6300	13.4833	0.1590	0.6700	0.9050	22.80	7.80	6.60	55.10
31	7/18/86	1810	H	HBPD	11.0400	16.5900	12.7200	13.4500	12.0000	11.7700	12.2400	12.0033	0.1100	0.4780	0.5750	22.30	7.80	7.10	54.90
34	7/21/86	512	L	NOSC	3.6900	3.1500		3.4200	8.4600	8.1900	8.4000	8.3500	0.0088	0.0153	0.0098	20.50	7.80	6.30	52.70
34	7/21/86	527	L	SWYC	11.8900	11.9800		11.9350	9.6300	10.7100	10.4400	10.2600	0.0395	0.0795	0.1245	20.00	7.80	7.50	52.20
34	7/21/86	547	L	SILVER	18.4000	31.4300	21.7600	23.8633	11.7800	11.6200	12.3000	11.9000	0.0596	0.2138	0.2880	20.50	7.80	5.80	52.60
34	7/21/86	601	L	HPBD	19.3400	26.6700	20.1200	22.0433	7.6700	7.3900	7.2500	7.4367	0.0316	0.0949	0.3495	19.00	7.80	7.00	51.30
42	7/29/86	1006	L	NOSC	8.7700	7.3800		8.0750	7.7800	6.3800	7.7200	7.2933	0.0060	0.0100	0.0160	21.00	7.80	6.90	53.20
42	7/29/86	1035	L	SWYC	18.8700	16.5100	19.2200	18.2000	19.5400	19.3100	18.7100	19.1867	0.1190	0.2120	5.2400	20.80	7.90	7.30	53.40
42	7/29/86	1706	H	SWYC	8.4600	8.3300	8.0800	8.2900	13.3000	12.6800	14.5000	13.4933	0.1320	0.1950	0.3580	21.50	7.80	8.00	53.80
42	7/29/86	1124	L	SILVER	16.9800	18.4900	17.6400	17.7033	10.3200	12.1300	11.9700	11.4733				21.50	7.90	7.10	53.80
42	7/29/86	1732	H	SILVER	9.4800	8.3700	10.4200	9.4233	11.3200	11.9200	11.7100	11.6500	0.1576	0.3200	0.5048	22.10	7.90	7.50	54.70
42	7/29/86	1150	L	HPBD									0.4200	0.1100	0.2060	21.10	7.90	7.90	53.50
42	7/29/86	1746	H	HPBD									0.1450	0.3020	0.7460	21.90	7.90	8.40	54.30
42	7/29/86	1442	H	NOSC	7.6400			7.6400	5.7700	5.7100	3.4900	4.9900	0.0130	0.0210	0.0230	21.10	7.70	7.30	53.40
42	7/29/86	1655	H	NOSC	4.2700	3.7100	3.2000	3.7267	8.1600	9.6500	7.7100	8.5067	0.0630	0.1140	0.2640	20.70	7.80	7.00	53.30
52	8/8/86	1143	H	NOSC	3.0600	1.6700		2.3650	5.1000	5.1300	3.9400	4.7233	0.0000	0.0100	0.0030				
52	8/8/86	805	H	NOSC	3.4800	3.3200	9.1300	5.3100	5.3100	7.2800	3.9300	5.5067	0.0070	0.0280	0.0170				
52	8/8/86	600	L	NOSC	3.0200	3.2600	3.5100	3.2633	5.5300	5.5100	4.0100	5.0167	0.0098	0.0385	0.0210				
52	8/8/86	611	L	SWYC	10.2000	9.4500	10.1200	9.9233	11.5600	11.6900	12.1800	11.8100	0.0470	0.1990	0.2360				
52	8/8/86	841	H	SWYC	7.4800	10.3400	8.1600	8.6600	10.5000	11.0000	9.9500	10.4833	0.0560	0.2110	0.2600				
52	8/8/86	1202	H	SWYC	6.5000	7.7100	9.3400	7.8500	11.8300	11.2600	10.5400	11.2100	0.0560	0.1710	0.1960				

day	date	time	tide	station	CuASV1	CuASV2	CuASV3	ASVave	CuICP1	CuICP2	CuICP3	ICPave	MBTL	DBTL	TBTL	temp	pH	DO	cond
52	8/8/86	628	L	SILVER	15.7800	20.3500	22.6700	19.6000	15.9000	16.0000	15.6700	15.8567	0.0640	0.2220	0.2900				
52	8/8/86	912	M	SILVER	5.0600	4.3100	5.4500	4.9400	6.5100	6.7200	6.8500	6.6933	0.0290	0.0830	0.0670				
52	8/8/86	1226	H	SILVER					11.4700	11.5800	10.2500	11.1000	0.0450	0.1650	0.1220				
52	8/8/86	651	L	HPBD	10.6400	9.2700	8.3900	9.4333	7.8300	7.6300	7.2200	7.5600	0.0400	0.2150	0.2210				
52	8/8/86	937	M	HPBD	5.1500	5.8000		5.4750	6.1000	6.8200	7.0400	6.6533	0.0420	0.1310	0.3220				
52	8/8/86	1249	H	HPBD	4.5200	4.3300		4.4250	4.7200	5.2800	5.7000	5.2333	0.0280	0.1000	0.1000				
63	8/19/86	427	L	NOSC	3.4000	2.6900	2.3500	2.8133	6.0200	4.5100	5.4000	5.3100	0.0050	0.0380	0.0180				
63	8/19/86	824	M	NOSC					6.6800	6.5100	7.6600	6.9500	0.0000	0.0270	0.0120				
63	8/19/86	1143	H	NOSC	2.3900	1.8500		2.1200	3.2100	5.0300	2.0700	3.4367	0.0000	0.0220	0.0280				
63	8/19/86	437	L	SWYC	8.7900	7.9300	8.9400	8.5533	9.7500	9.4300	10.8900	10.0233	0.0230	0.2360	0.2880				
63	8/19/86	836	M	SWYC	5.0900	5.7200	6.9200	5.9100	8.8800	8.7900	9.5800	9.0833	0.0000	0.1200	0.2120				
63	8/19/86	1156	H	SWYC	6.1600			6.1600	12.1200	11.2100	11.5400	11.6233	0.0260	0.2490	0.2560				
63	8/19/86	455	L	SILVER	18.7500	23.6900	23.5700	22.0033	22.8100	23.5400	21.6600	22.6700	0.0450	0.5530	0.8050				
63	8/19/86	854	M	SILVER	11.3000	12.2600	10.8100	11.4567	12.1100	11.7800	12.7700	12.2200	0.0150	0.3500	0.5620				
63	8/19/86	1214	H	SILVER	10.9200	8.1900	9.1300	9.4133	9.4000	8.1300	9.1400	8.8900	0.0250	0.6090	0.9240				
63	8/19/86	510	L	HPBD	7.0300	6.7700	6.2200	6.6733	6.2700	6.2600	6.0500	6.1933	0.0160	0.1650	0.2370				
63	8/19/86	907	M	HPBD	5.1100	4.3400	4.0800	4.5100	5.0800	6.1100	6.0100	5.7333	0.0000	0.1350	0.1990				
63	8/19/86	1227	H	HPBD	3.6400	3.0500	3.7800	3.4900	3.1600	2.9900	3.3200	3.1567	0.0000	0.0890	0.1090				
93	9/16/86	912	H	NOSC									0.0310	0.0400	0.0610				
93	9/16/86	1158	M	NOSC									0.1140	0.1090	0.1350				
93	9/16/86	1500	L	NOSC									0.0390	0.0570	0.0570				
93	9/16/86	1207	M	SWYC									0.1340	0.1390	0.1480				
93	9/16/86	1512	L	SWYC									0.1480	0.3350	0.1680				
93	9/16/86	924	H	SWYC									0.0780	0.2430	0.3110				
93	9/16/86	940	H	SILVER									0.2480	0.4330	0.3680				
93	9/16/86	1222	M	SILVER									0.1860	0.6800	0.3080				
93	9/16/86	1526	L	SILVER									0.2320	0.4120	0.2990				
93	9/16/86	951	H	HPBD									0.1780	0.1990	0.1730				
93	9/16/86	1231	M	HPBD									0.1160	0.1210	0.0980				
93	9/16/86	1538	L	HPBD									0.1970	0.2140	0.0820				
182	12/16/86	831	H	NOSC	0.8200			0.8200	4.3500	5.2500	2.4300	4.0100	0.0070	0.0050	0.0080	16.00			
182	12/16/86	848	H	SWYC	6.1600	5.7400		5.9500	9.1800	7.7500	8.3100	8.4133	0.0920	0.1690	0.2650	16.00			
182	12/16/86	857	H	SILVER	8.8200	13.5100	9.0500	10.4600	8.8100	7.9400	9.2700	8.6733	0.0710	0.2880	0.3500	16.00			
182	12/16/86	831	H	HPBD	1.3500			1.3500	1.8200	3.0200	2.4400	2.4267	0.0130	0.0300	0.0520	16.00			

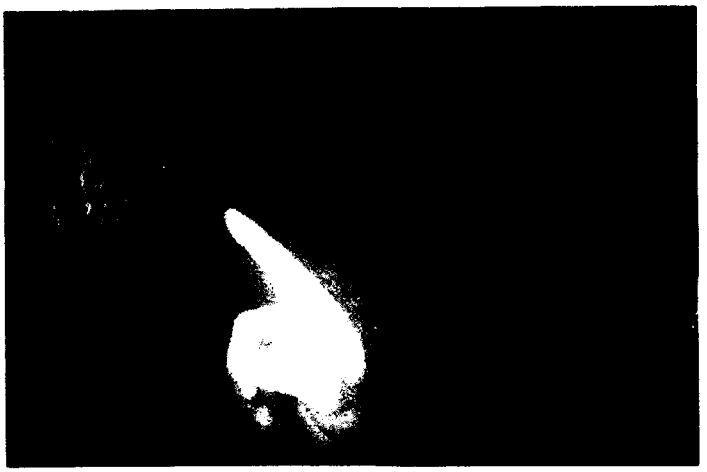
day	date	time	tide	station	CuASV1	CuASV2	CuASV3	ASVave	CuICP1	CuICP2	CuICP3	ICPave	MBTL	DBTL	TBTL	temp	pH	DO	cond
182	12/16/86	1155	M	NOSC	1.3600			1.3600	4.2400	4.8000	5.7600	4.9333	0.0100	0.0100	0.6800	16.50			
182	12/16/86	1155	M	SWYC	5.9300	6.8900		6.4100	11.0400	10.1400	11.1500	10.7767	0.0510	0.2430	0.3110	17.00			
182	12/16/86	1157	M	SILVER	9.0600	8.2900	12.1600	9.8367	13.5900	13.9800	13.7700	13.7800	0.1210	0.3670	0.4440	17.50			
182	12/16/86	1200	M	HPBD	2.1500	2.6000		2.3750	4.1800	3.9500	4.0700	4.0667	0.0390	0.1090	0.1810	17.50			
182	12/16/86	1555	L	NOSC	1.6500			1.6500	6.3600	3.6000	5.3300	5.0967	0.0060	0.0110	0.0260	17.00			
182	12/16/86	1555	L	SWYC	6.3600	9.9200	9.4200	8.5667	11.3800	10.4600	11.6300	11.1567	0.0610	0.3430	0.5090	17.00			
182	12/16/86	1557	L	SILVER	7.4900	8.9300	7.7200	8.0467	11.0500	11.9500	11.7000	11.5667	0.1020	0.3950	0.5420	18.00			
182	12/16/86	1558	L	HPBD	5.5300	4.5300		5.0300	7.0400	7.7500	7.4900	7.4267	0.0730	0.2310	0.1990	17.00			
220	1/23/87	1100	L	NOSC	2.3100	2.0000		2.1550	2.5300	5.4000	3.5800	3.8367	0.0110	0.0180	0.0510	13.70	8.20	7.10	44.50
220	1/23/87	1140	L	SWYC	7.4500	5.5700	5.9700	6.3300	8.8100	9.2000	10.0100	9.3400	0.0610	0.2150	0.2070	14.70	8.20	7.10	44.50
220	1/23/87	1154	L	SILVER	12.5000	10.0600	10.5900	11.0500	10.3000	10.1100	9.4700	9.9600	0.0990	0.3630	0.4140	13.70	8.30	7.50	45.10
220	1/23/87	1204	L	HPBD	5.6200	4.9700	4.6800	5.0900	6.1400	6.0400	5.2500	5.8100	0.0470	0.2050	0.2910	13.70	8.80	7.00	44.40
220	1/23/87	1633	H	NOSC	0.8000	1.8100	2.0400	1.5500	5.5000	4.3100	5.5800	5.1300	0.0100	0.0150	0.0230	14.50	8.30	7.50	45.10
220	1/23/87	1645	H	SWYC	3.2200	6.2600	6.8600	5.4467	9.5500	9.1200	10.0400	9.5700	0.0610	0.2040	0.2070	14.00	8.20	7.60	44.60
220	1/23/87	1702	H	SILVER	7.2500	7.6200	10.7000	8.5233	11.7700	11.6700	11.8200	11.7533	0.1000	0.3050	0.2310	14.00	8.30	7.30	44.80
220	1/23/87	1714	H	HPBD	4.2900	4.0900		4.1900	4.9100	3.5000	4.8200	4.4100	0.0600	0.1240	0.1520	14.00	8.30	7.70	44.70
	9/19/87	900	H	NOSC	3.6600	3.7300	2.2900	3.2267	2.2500	2.1300	2.4400	2.2733				21.20	7.80	7.50	53.20
	9/19/87	1426	L	NOSC	2.7900	2.9900	3.4800	3.0867	1.8200	1.8900	2.1500	1.9533				21.10	7.90	8.10	53.30
	9/19/87	910	H	SWYC	9.0100	9.4600	8.0000	8.8233	8.2600	8.7700	9.1500	8.7267				21.60	7.80	7.50	53.60
	9/19/87	1338	L	SWYC	10.9200	12.3100	10.2000	11.1433	8.5600	9.0100	8.0500	8.5400				22.40	7.80	8.00	54.30
	9/19/87	926	H	SILVER	11.6800	10.0500	10.3100	10.6800	9.6100	9.0900	9.8900	9.5300				22.00	7.80	7.00	53.90
	9/19/87	1355	L	SILVER	11.5000	12.7900	9.9900	11.4267	9.0300	10.7300	10.0000	9.9200				22.70	7.80	7.80	54.80
	9/19/87	937	H	HPBD	8.0900	8.8300	6.7200	7.8800	7.7100	7.4100	8.5000	7.8733				21.60	7.80	7.50	53.80
	9/19/87	1404	L	HPBD	6.8800	8.0000	8.5400	7.8067	7.9100	7.4300	8.4800	7.9400				22.30	7.80	8.00	54.30
	8/15/86	CNTL		TANK 2	4.2200	3.9700		4.0950	5.6600	5.9200	6.2500	5.9433							
	8/15/86	CNTL		TANK 5	5.0600			5.0600	6.4500	6.2000	6.2300	6.2933							
	8/15/86	CNTL		TANK 9	4.7900	4.6800		4.7350	4.3100	4.9100	7.0300	5.4167							
	8/15/86	100 %		TANK 1	7.6600	8.3000	7.2700	7.7433	8.1000	7.1500	10.8400	8.6967							
	8/15/86	100 %		TANK 11	5.3100	5.5600		5.4350	6.2800	8.2100	7.1400	7.2100							
	8/15/86	100 %		TANK 12	6.5800	5.4100		5.9950	7.9800	6.0800	4.9300	6.3300							
	8/15/86	25 %		TANK 3	5.3000	4.4500		4.8750	8.4300	7.0100	8.1100	7.8500							
	8/15/86	25 %		TANK 8		6.4200	4.5400	5.4800	6.0400	7.2600	4.5800	5.9600							
	8/15/86	25 %		TANK 10	5.1900	5.8800		5.5350	6.4700	6.8100	6.5200	6.6000							

day	date	time	tide	station	CuASV1	CuASV2	CuASV3	ASVave	CuICP1	CuICP2	CuICP3	ICPave	MBTL	DBTL	TBTL	temp	pH	DO	cond
	8/15/86	10	%	TANK 4	5.0200			5.0200	5.1600	6.0900	4.7600	5.3367							
	8/15/86	10	%	TANK 6	4.9200	5.4000		5.1600	5.2400	4.4000	6.2600	5.3000							
	8/15/86	10	%	TANK 7	7.5700	4.8500	7.8000	6.7400	7.7100	7.4500	7.1400	7.4333							
	8/15/86			DOCK	2.9100	3.4700		3.1900	6.4100	5.5200	4.5700	5.5000							

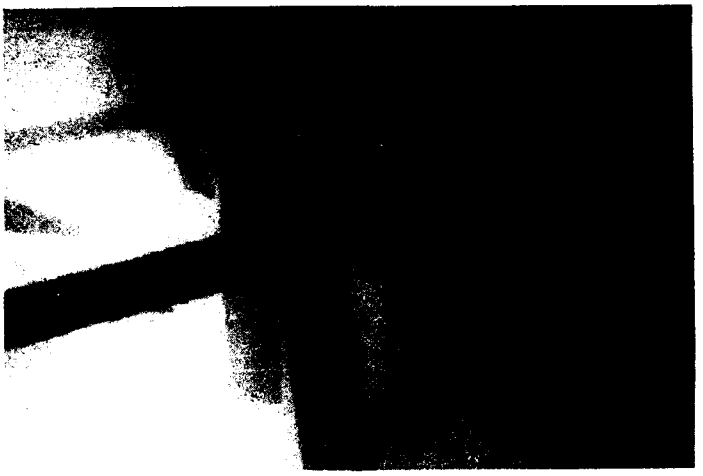
APPENDIX C

PHOTOGRAPHS OF FOULING PANELS

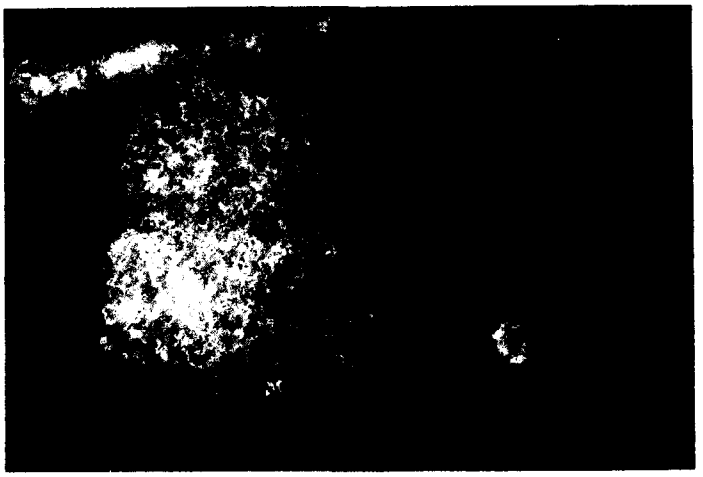
Photographs were obtained from fouling panels deployed at the Naval Ocean Systems Center (NOSC) pier 159, the Harbor Police Boat Dock (HPBD), slip D-62 of the Southwestern Yacht Club (SWYC), and the dock at the Silvergate Yacht Club (SILVER) in Shelter Island Yacht Basin (figure 1). Underwater photographs were taken with a Nikonus camera with a macro lens and strobe. The other photographs were taken with a Nikon 35-mm camera with a 50-mm 1:1.8 lens.



(A)



(B)



(C)

Figure C-1. The author using SCUBA to examine fouling panel array located under the dock at the SWYC station (A). Fouling panel attached to fouling panel array (B). Fouling panel array suspended beneath the dock at the SWYC station (C). (Photographs by A. Jones.)

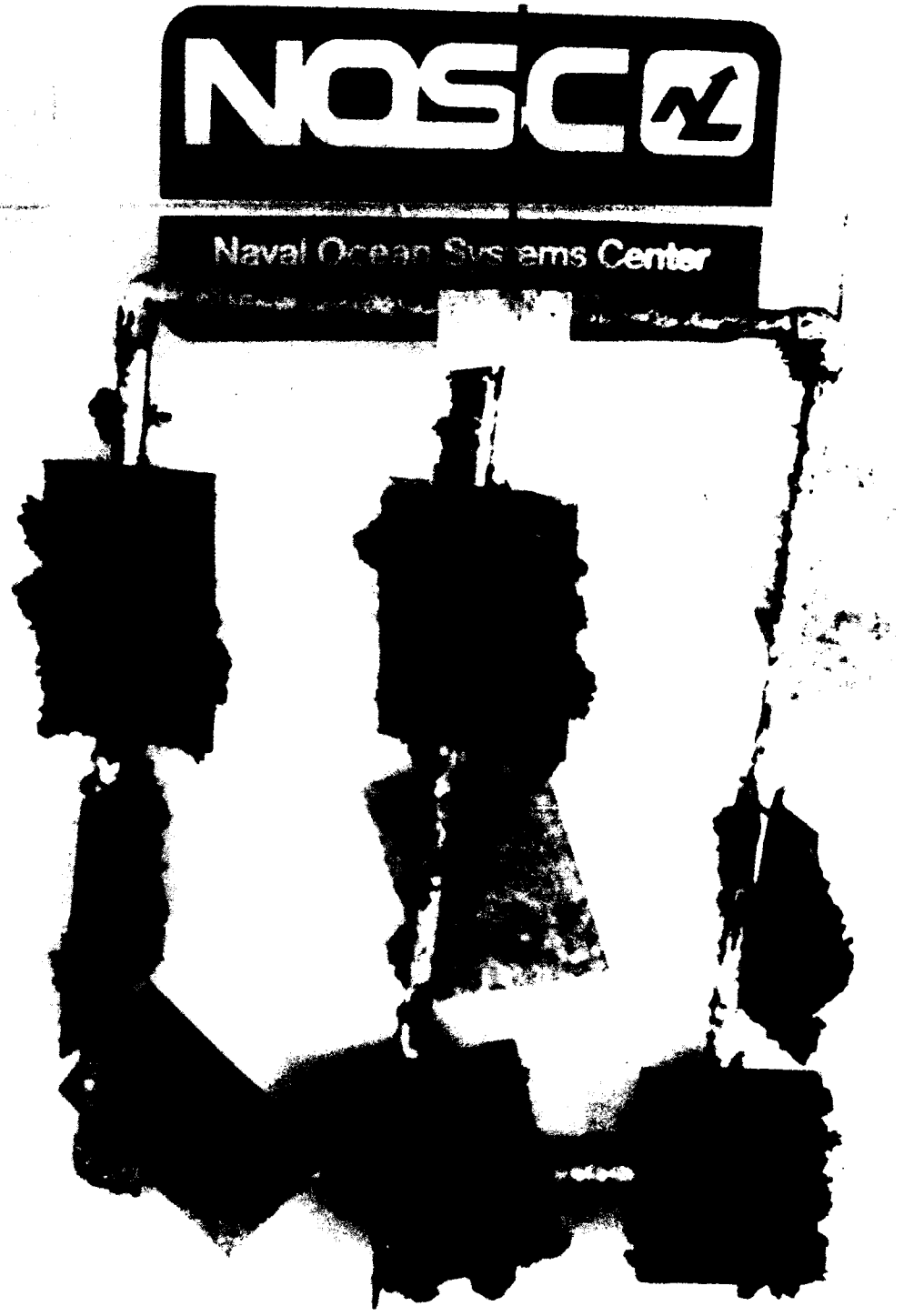


Figure C-2. Fouling panel array retrieved from the NOSC station showing the three panels that were exposed for 3 weeks and the six panels that were exposed for 9 weeks.

(A) (B) (C)

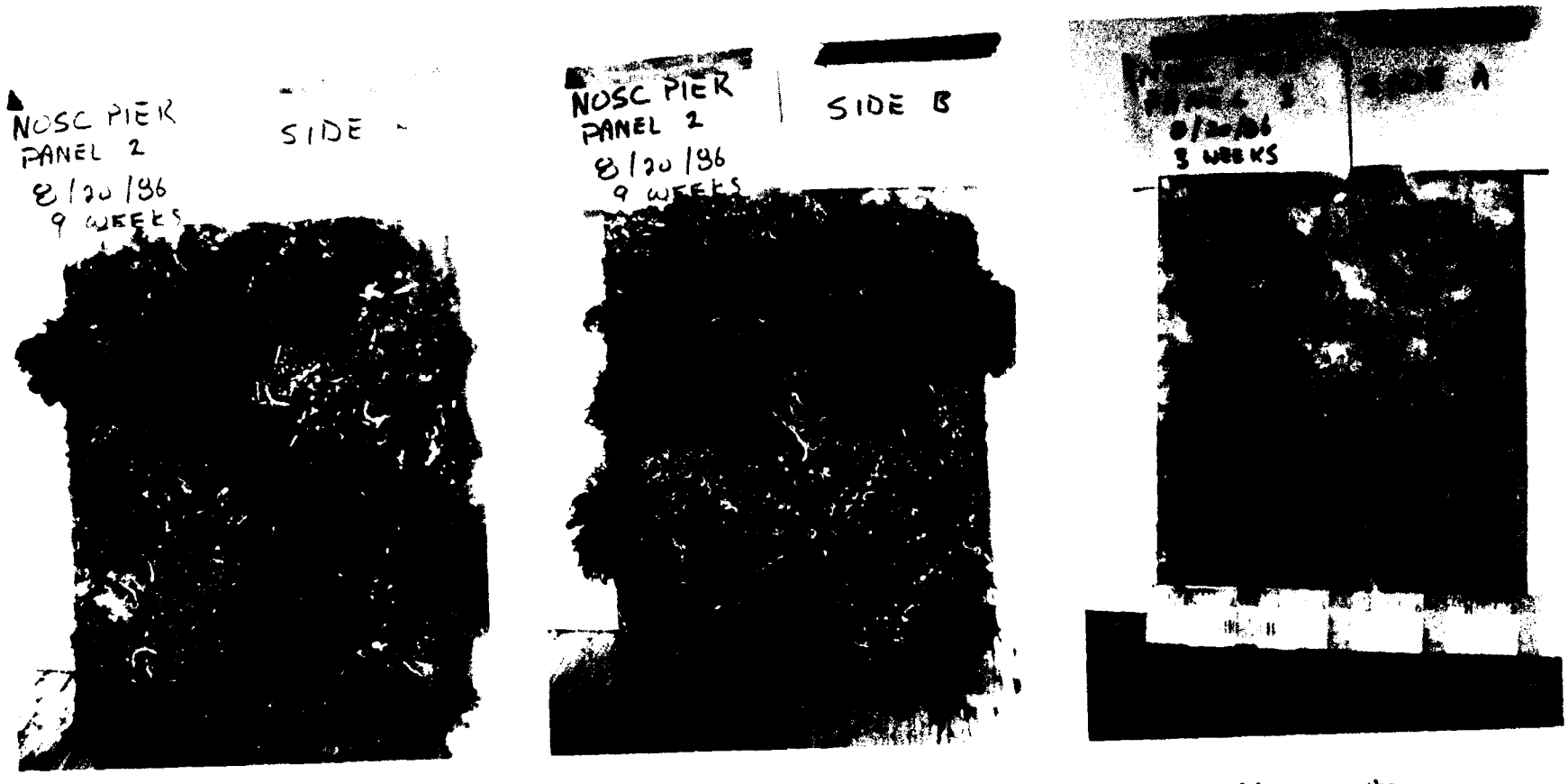


Figure C-3. Fouling panel exposed for 9 weeks at the NOSC station (A) and (B). The panel had large growths of *Bugula californica* and *B. neritina*. Also present in relatively high density were the tube building polychaetes *Hydroides pacificus* and *Spirorbis* sp.; the tunicates *Botryllus* spp., *Ciona intestinalis*, and *Diplosoma* spp., the bryozoans, *Watersipora* sp. and *Holloperella brunnea*; and the amphipod, *Ericthonius brasiliensis*. The same species were present, although in lower numbers and density, on the panel exposed for 3 weeks (C).

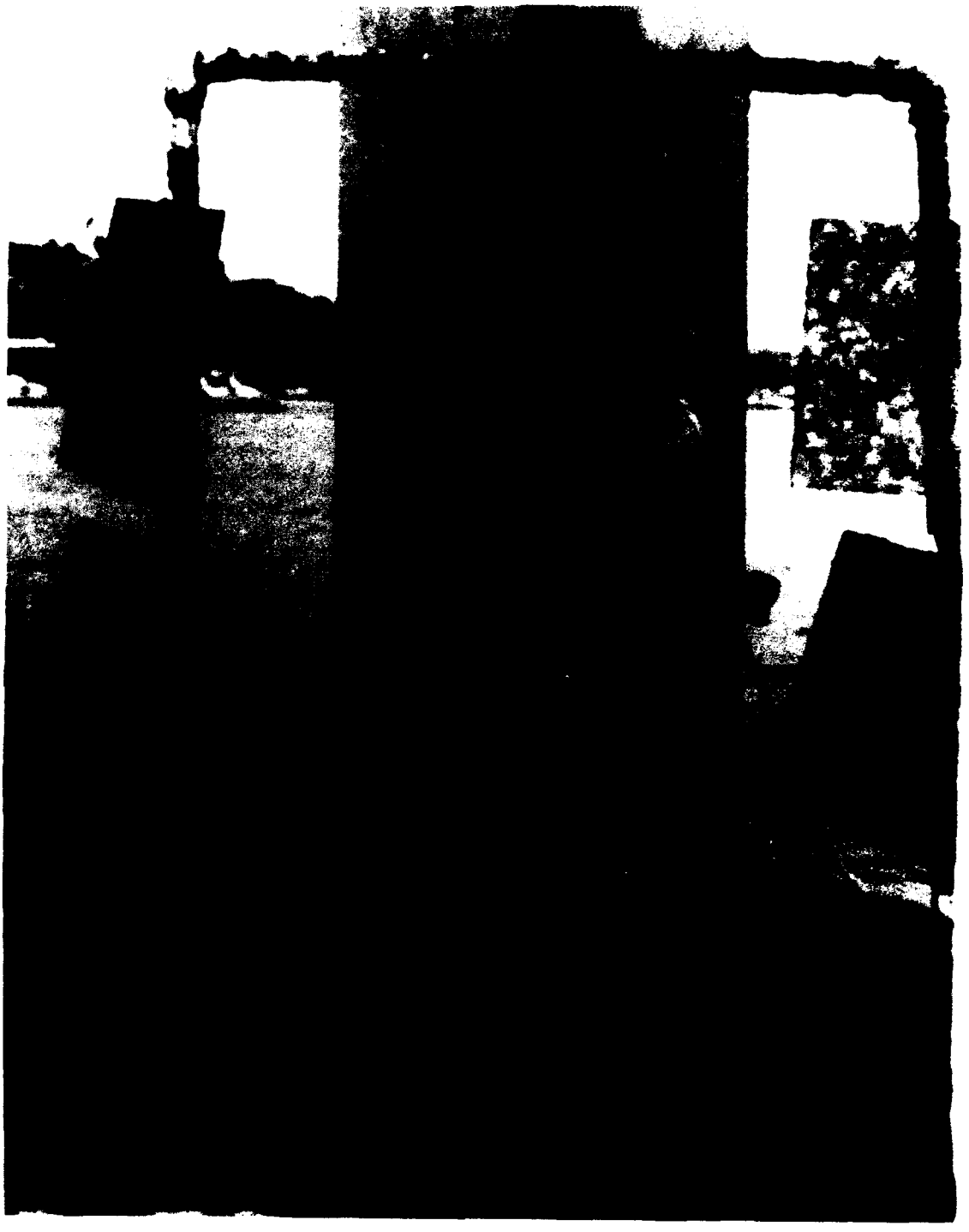


Figure C-4. The fouling panel array collected from the HPBD station showing panels exposed for 3 and 9 weeks.

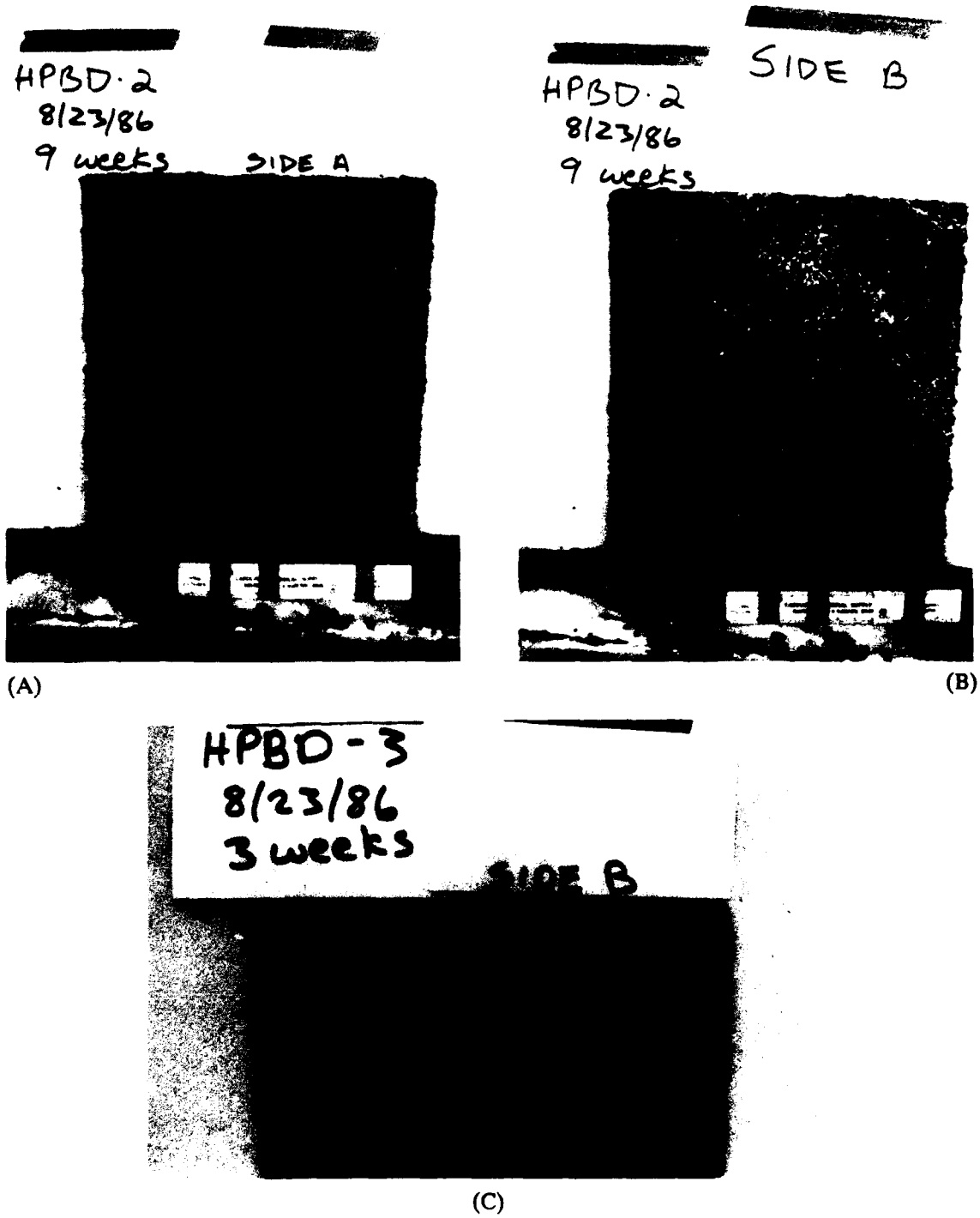


Figure C-5. Fouling panel exposed for 9 weeks at the HPBD station (A and B). The polychaetes, *Hydroides pacificus* and *Spirorbis* sp., are interspersed with patches of *Bugula* spp. and *Diplosoma* spp. Many individuals of *Hydroides pacificus* and *Spirorbis* sp. were present on the panel exposed for 3 weeks (C).

Figure C-6. The fouling panel array collected for the SWYC station showing panels exposed for 3 and 9 weeks. Intense colonization by *Hydroides pacificus* occurred at this station.

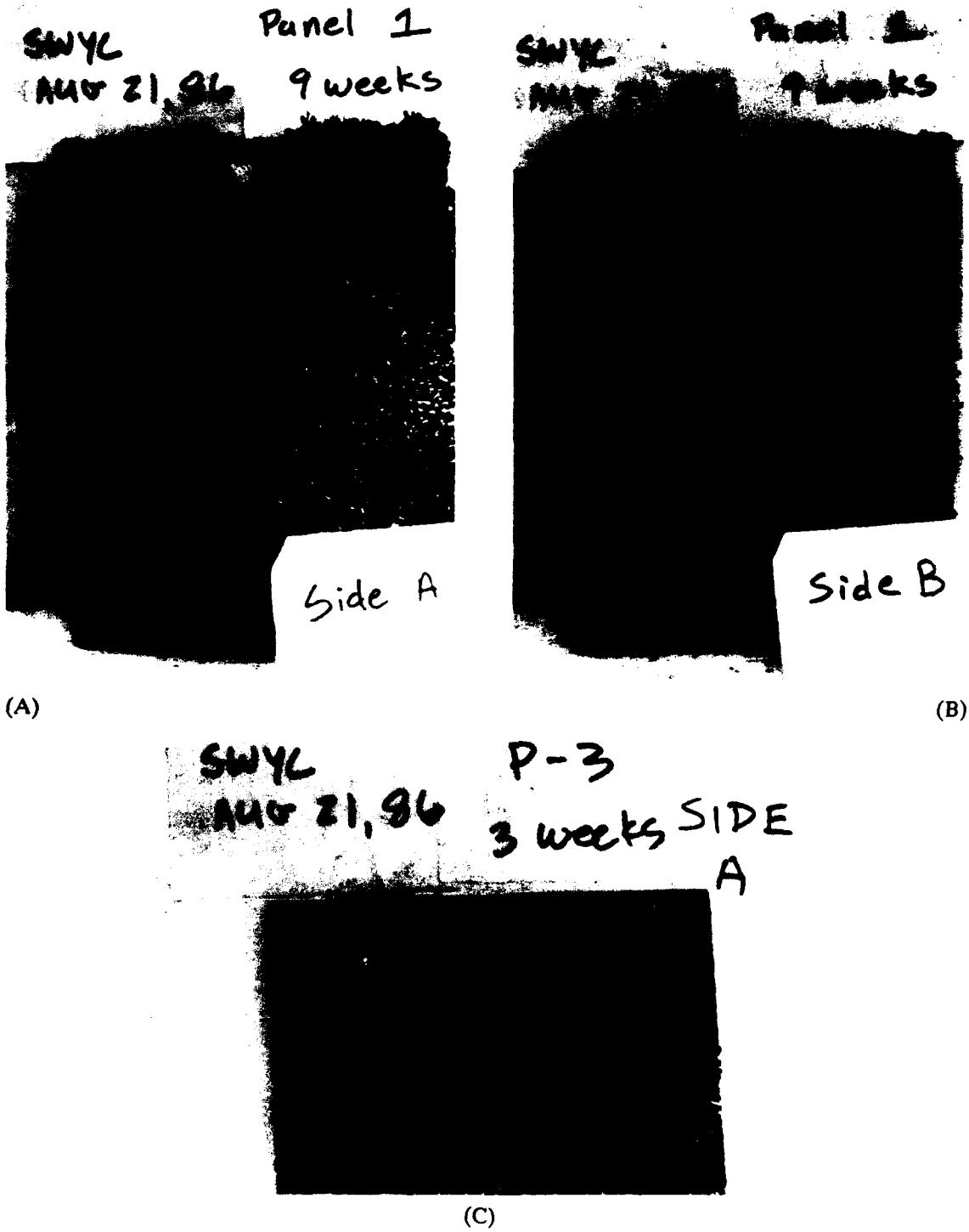


Figure C-7. A fouling panel exposed for 9 weeks at the SWYC station (A and B). The high biomass density was dominated by *H. pacificus*. A fouling panel exposed for 3 weeks shows many *H. pacificus* and *Spirorbis* sp. individuals (C).

Figure C-8. The fouling panel array collected from the SILVER station showing panels exposed for 3 and 9 weeks.

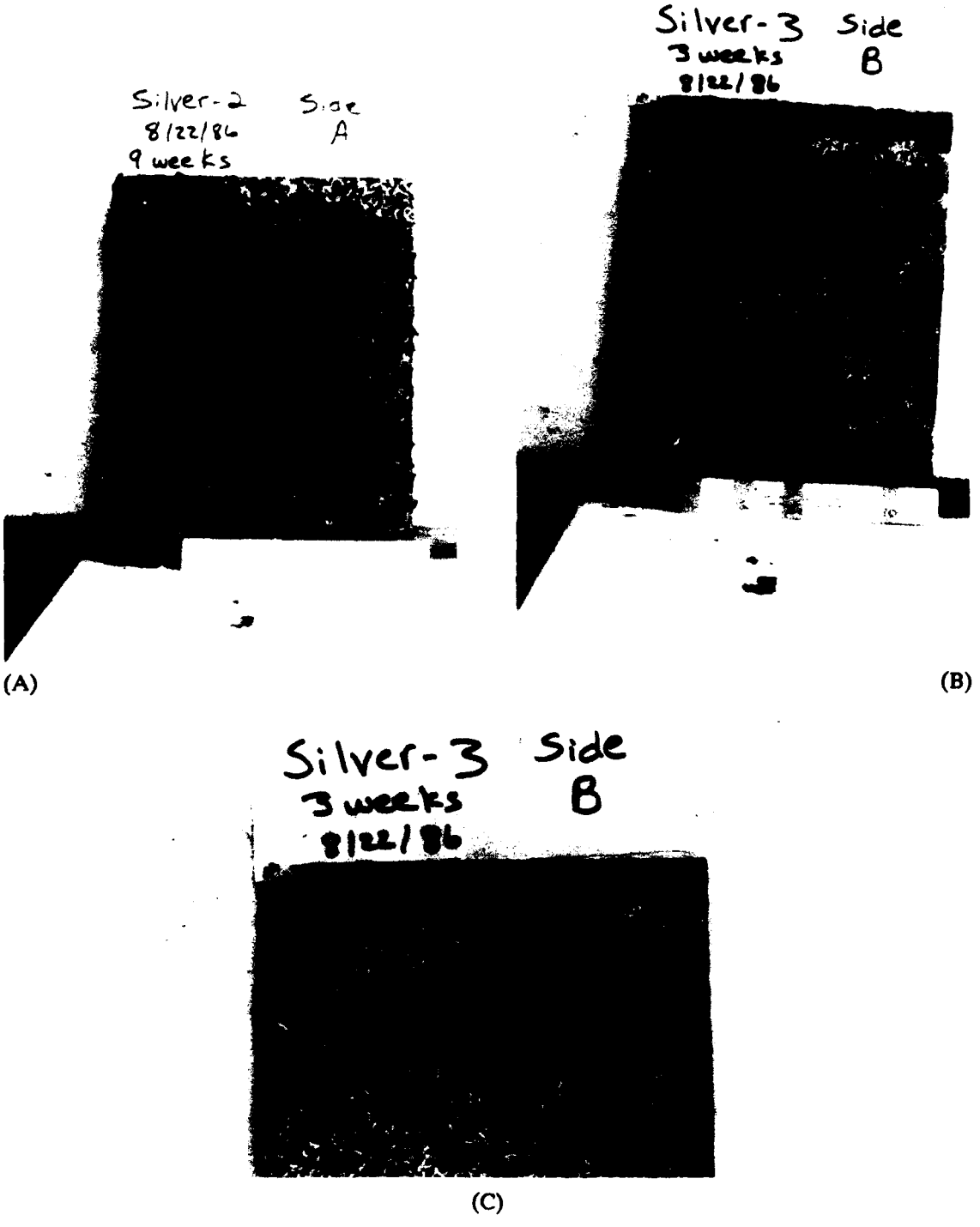


Figure C-9. A fouling panel exposed for 9 weeks (A and B) and 3 weeks (C) at the SILVER station. The polychaetes, *H. pacificus* and *Spirorbis* sp., dominated the community present.

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	June 1990	Final

4. TITLE AND SUBTITLE

USE OF MARINE FOULING COMMUNITIES TO EVALUATE THE ECOLOGICAL EFFECTS OF POLLUTION

5. FUNDING NUMBERS

OMN
PE: 63271N
WU: DN307504

6. AUTHOR(S)

R. K. Johnston

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

Naval Ocean Systems Center
San Diego, CA 92152–5000

8. PERFORMING ORGANIZATION REPORT NUMBER

NOSC TR 1349

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

Naval Facilities Engineering Command
200 Stovall Street
Alexandria, VA 22332

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT

Approved for public release; distribution is unlimited.

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

The ecological consequences of pollution were evaluated by measuring the biological responses of marine fouling communities to increasing levels of pollution in San Diego Bay, California. Measurements of a gradient of increasing levels of copper and organotin compounds were made using anodic stripping voltammetry and inductively coupled plasma spectroscopy for copper and hydride derivation with atomic spectroscopy detection for the organotin compounds tributyltin (TBT), dibutyltin, and monobutyltin. The copper gradient increased by a factor of 4.2 and the TBT gradient increased by a factor of 8.75. Differences in community structure were correlated with distinctly higher concentrations of toxic chemicals present at locations along the gradient. A portable microcosm system was used to study the community responses to different concentrations of TBT in controlled environments. The microcosm study was inconclusive because there was very low settlement of fouling organisms in the microcosm tanks relative to their settlement and colonization in the bay.

14. SUBJECT TERMS

marine fouling, tributyltin (TBT), dibutyltin (DBT), monobutyltin (MBT), anodic stripping voltammetry (ASV), inductively coupled plasma spectroscopy (ICP), pollution, ecological effects, microcosm, copper, cupric ion

15. NUMBER OF PAGES

120

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED	SAME AS REPORT